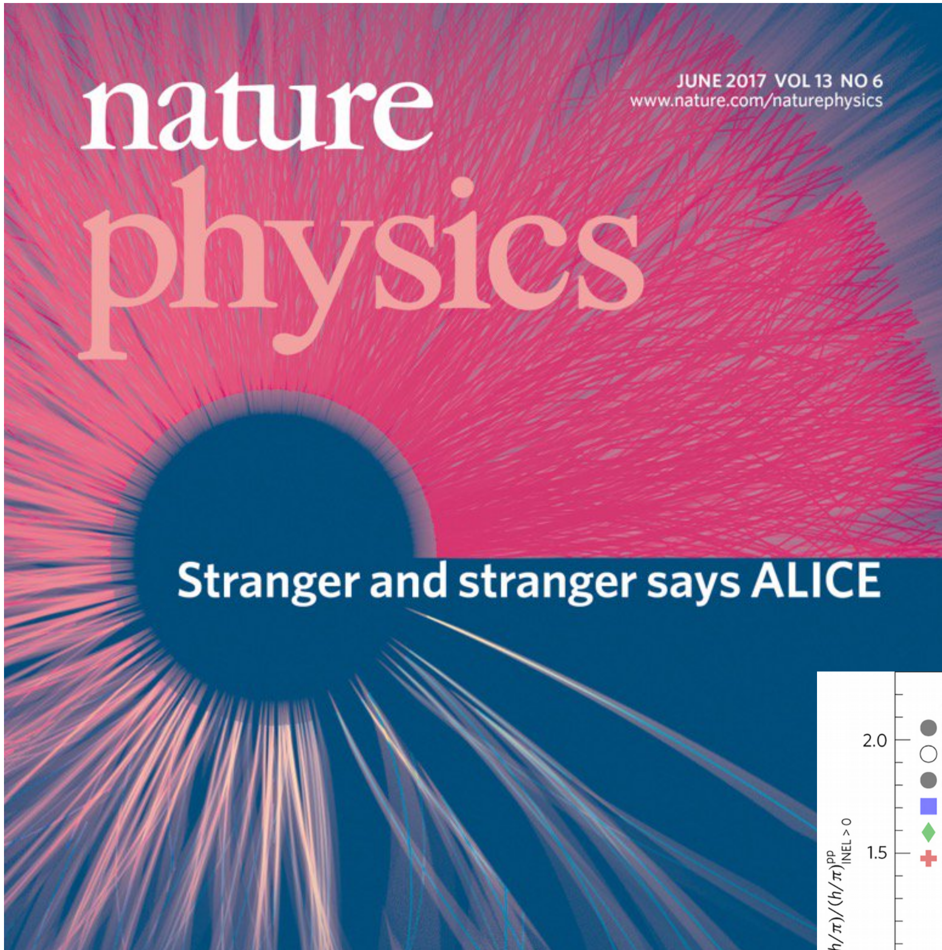
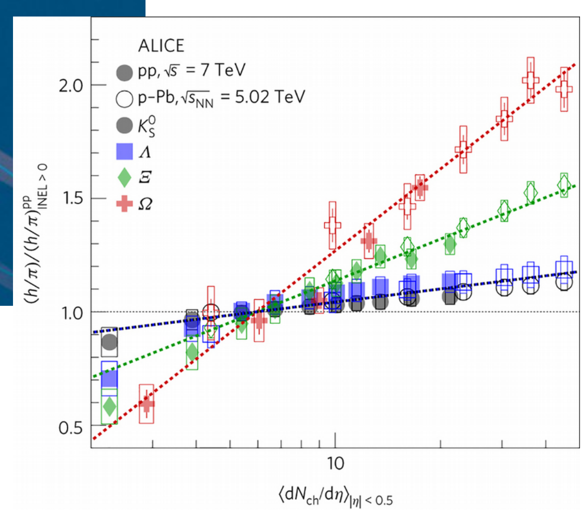


A smoking-gun of
quark-gluon plasma …

into the territory
of (high-multiplicity)
proton-proton collisions



Institut Pluridisciplinaire Hubert Curien STRASBOURG

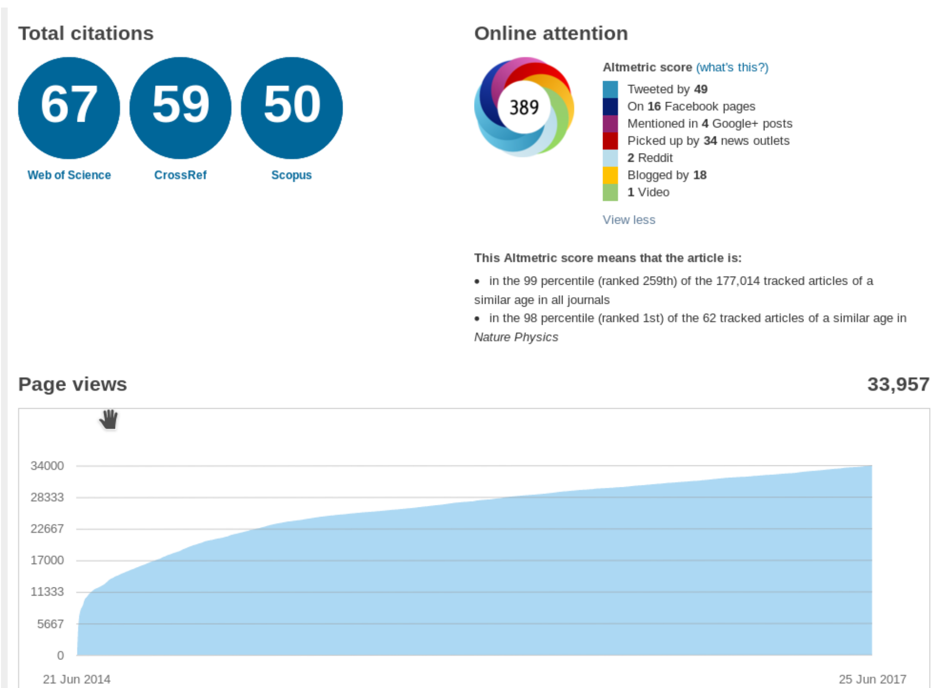
Foreword : the fuss

<u>CMS</u>

Higgs coupling to fermions ($H \longrightarrow bb, \tau\tau$)

https://arxiv.org/abs/1401.6527

DOI:10.1038/nphys3005

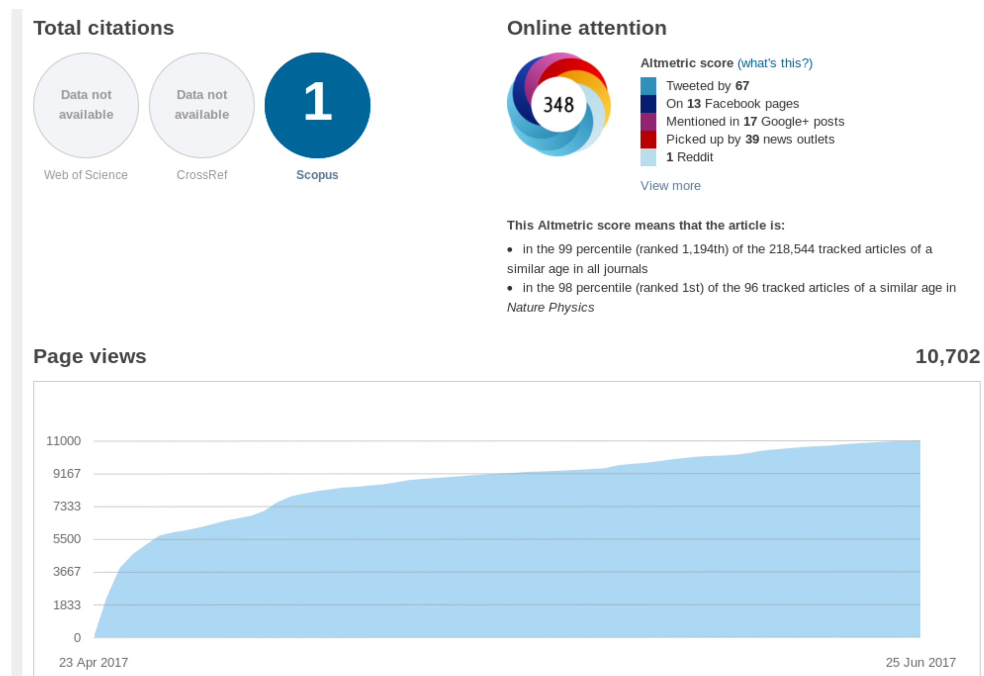


<u>ALICE</u>

Strangeness enhancement in pp

https://arxiv.org/abs/1606.07424

DOI:10.1038/nphys4111



Outline

ArXiv : arXiv-1606.07424
DOI : 10.1038/nphys4111
HEPdata : record-77284
ALICE figs : aliceinfo.cern.ch-node/2929

I. Introduction : QGP research and context

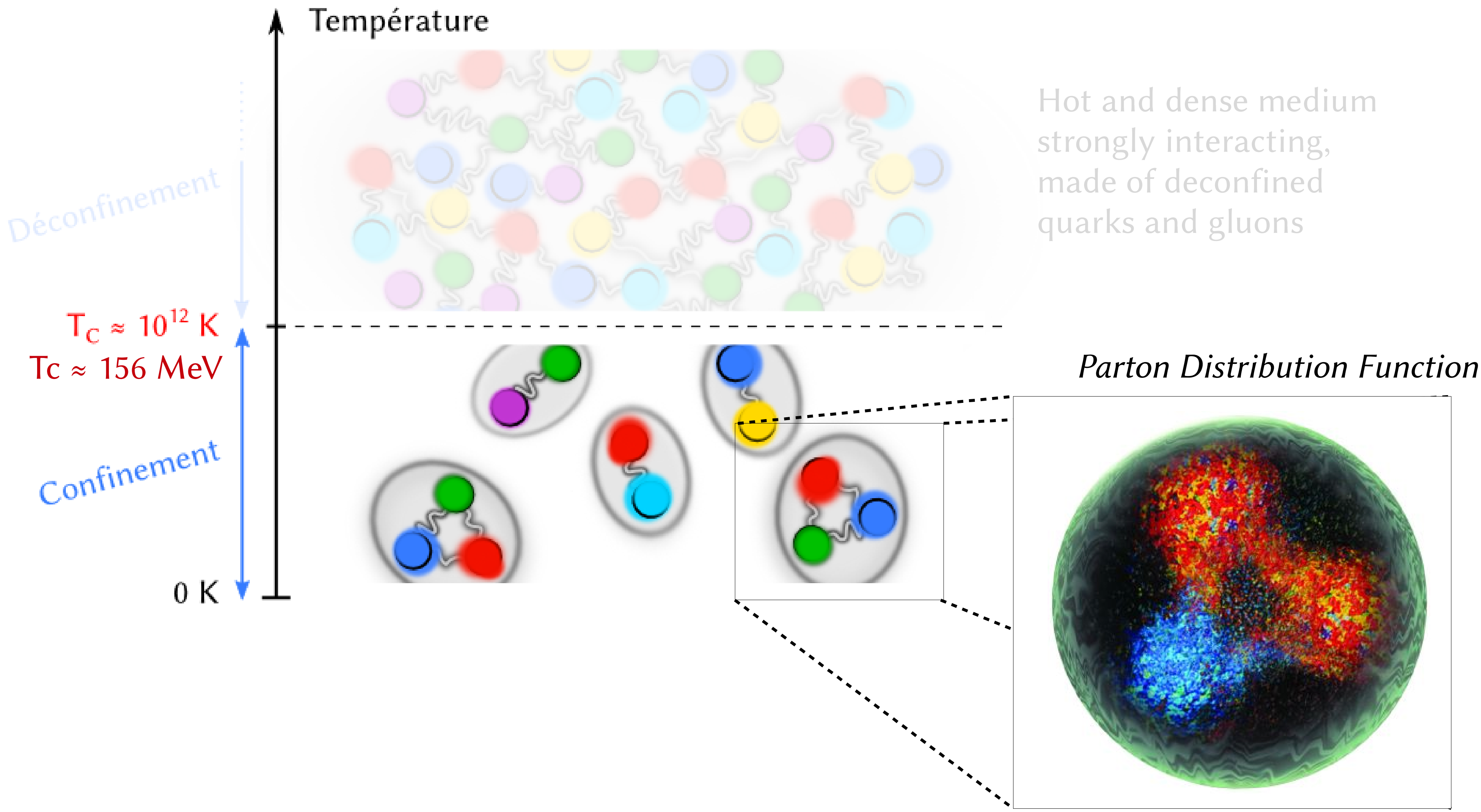
Part A - Strangeness enhancement in A-A

II. Chiral symmetry
III. Event activity and centrality
IV. Strangeness enhancement, concept and experiment

Part B - Strangeness enhancement in high-multiplicity pp

V. Principle of the pp measurement
VI. Results : p_{T} spectra = f(multiplicity)
VII. Results : dN/dy = f(multiplicity)
VIII. Glimpse into the phenomenology counterparts

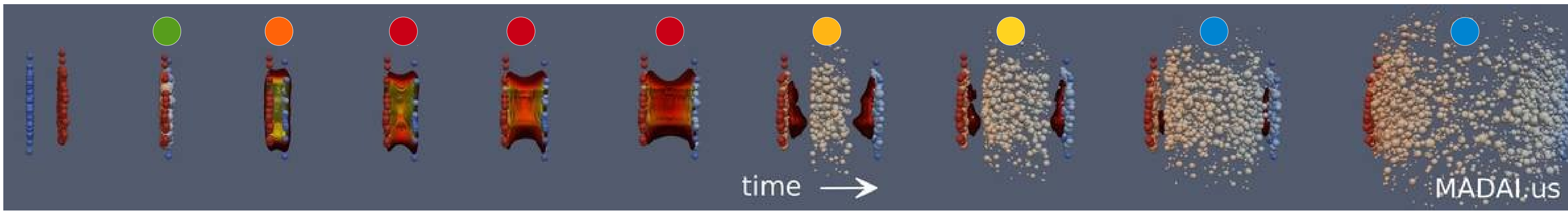
I.1 – Introduction : QCD phase transition

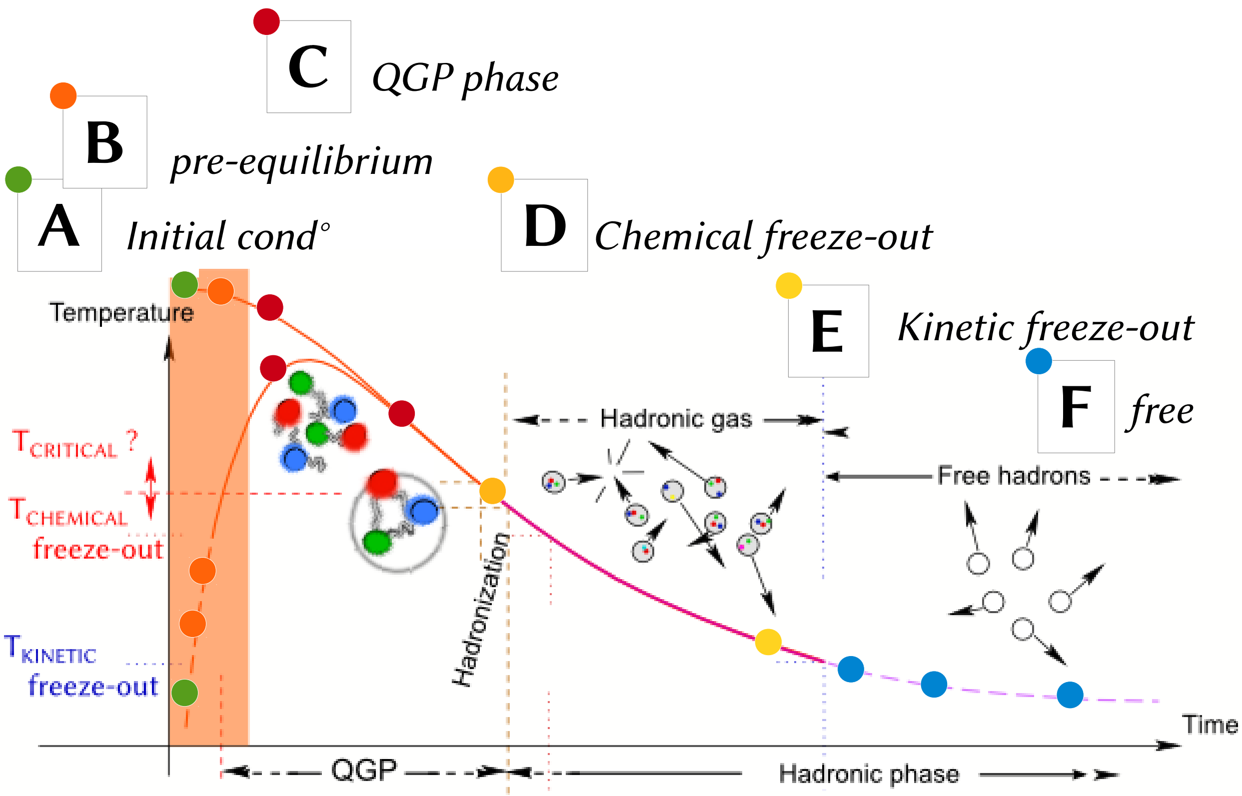


DOI : 10.1103/PhysRevD.27.140

I.2 – Intro. : Bjorken scenario in heavy-ion collisions

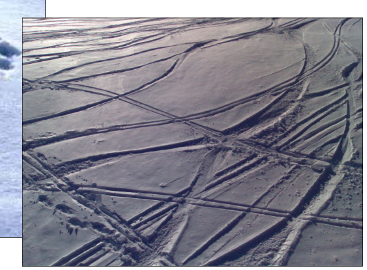
Courtesy of MADAI.us (see animation movie !)





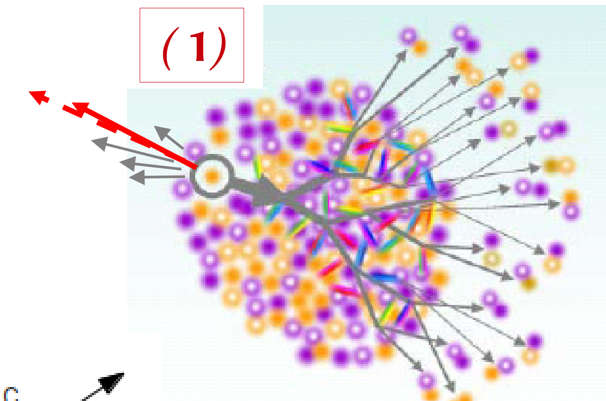
→ Remark :

No such thing as a live vision !
but always, an observation based on remnants from the past …



(NB : physics ~ 10^{-23} s / electronic readout > 10^{-12} s)

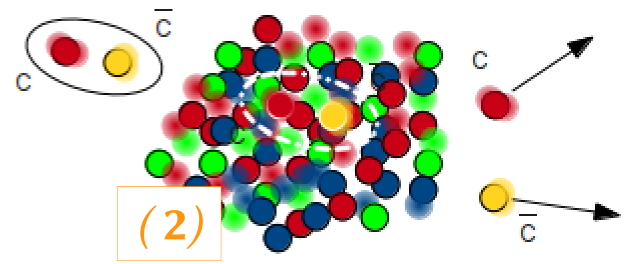
I.3 – Intro. : major probes of QGP



The 4 main signatures/characterisation probes of QGP :

~ pQCD
Hard processes

1/ hard processes and in-medium energy loss QGP
high-p_T/ jet physics



2/ quarkonia ($c\bar{c}$, $b\bar{b}$) melting

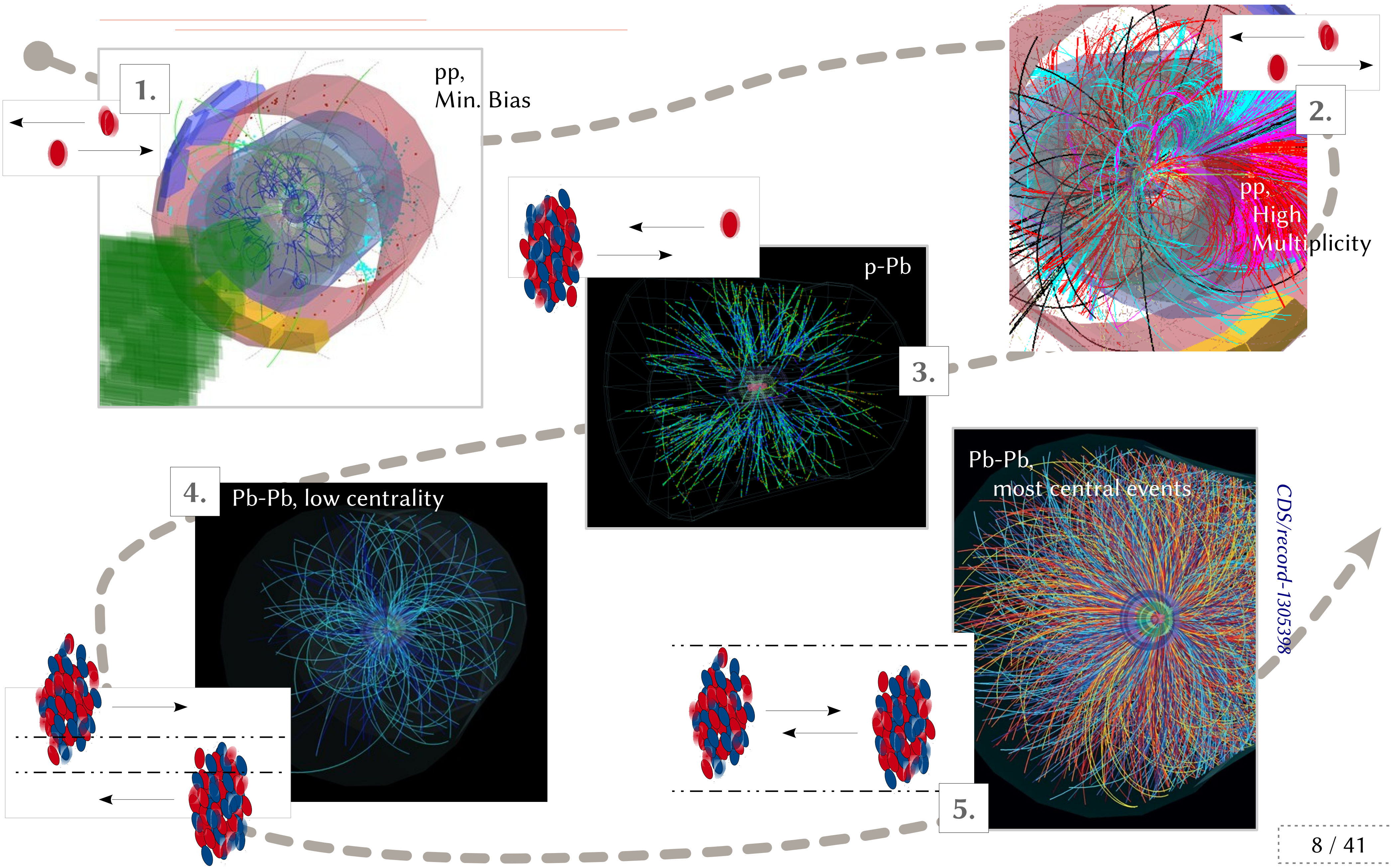
3/ relativistic (nearly perfect) hydrodynamics

~ pheno. QCD
Soft processes

4/ hadrochemistry and *flavour* physics :

u,d,s,c,b (t) <=> $\pi^\pm$, π^0, $K^\pm$, K^0_S, ... , p, Λ, Ξ^-, Ω^-, ... η, $K^0(892)$, $\phi(1020)$, $\Sigma^\pm(1385)$, $\Xi^0(1530)$
D^0, $D^\pm$, $D^{*\pm}$, D_S^+, J/ψ, χ_{Ci}, $\psi(2S)$, ... , Λ_C, B^0, $B^\pm$, B^0_S, $\Upsilon(1S,2S,3S)$,
γ, $W^\pm$, Z^0
d, t, ${}^3_\Lambda H$, ${}^3He$, ${}^4He$, ... + anti-particles

I.4 – Intro. : pp, pA, AA, continuum of physics ?



I.4 – Intro. : pp, pA, AA, continuum of physics ?

→ QGP physics can start with a *plain* question :
at the same $\sqrt{s_{NN}}$, " 1 x (Pb-Pb) ≠ *N* x (pp) ? "

first plot : "Pb-Pb = QGP" vs. "pp Min Bias = no QGP"

A plot to be qualified ... :

($dN_{ch}/d\eta \approx 30$) in semi-central Cu-Cu at $\sqrt{s_{NN}}$ = 200 GeV, *i.e. in presence of QGP*	≈	$dN_{ch}/d\eta$ in high-multiplicity pp at $\sqrt{s}$ = 7 TeV

(See STAR, $dN_{ch}/d\eta$ in Cu-Cu, arXiv:1008.3133
+ *STAR data*)

i.e. equivalent energy released into the collisions

Question : **"strong collective interactions" in pp ?**

i.e. an AA-like behaviour ?
Even, a QGP-like behaviour... ?!
Or, at least, something that is not present in e^+e^- ?

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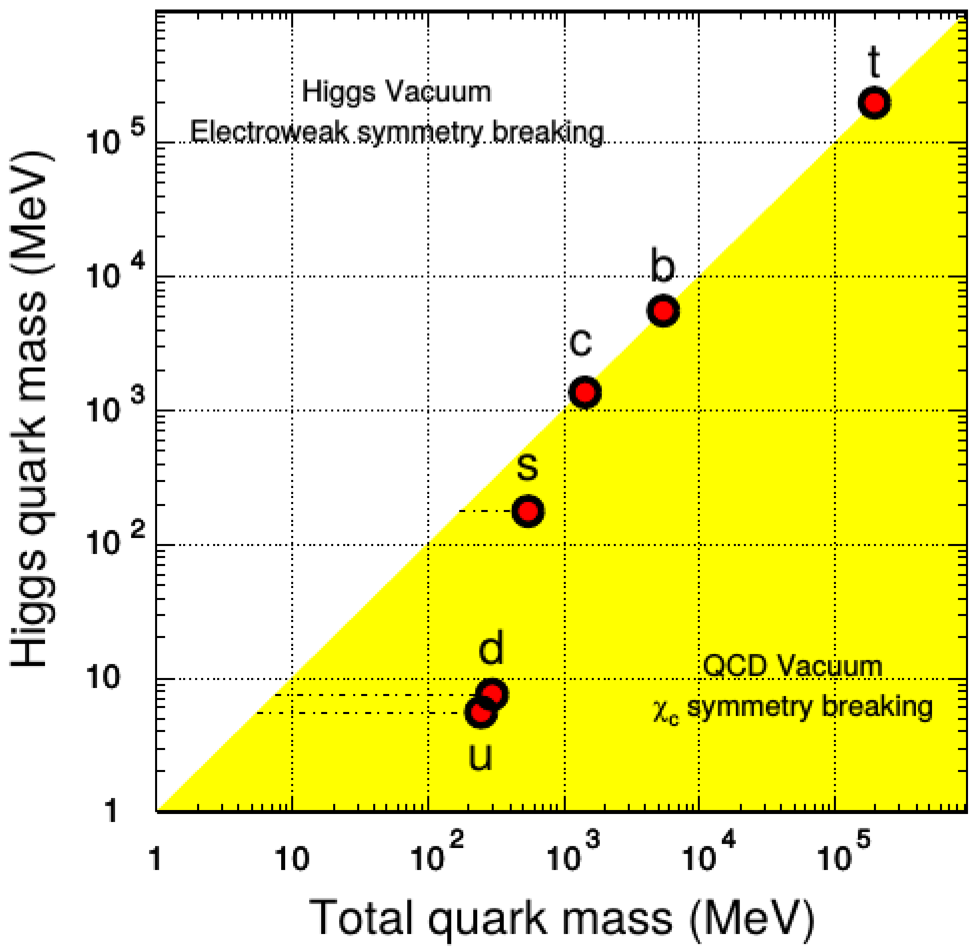
II.1 – Chiral symm. : bare vs. constituent mass

arXiv:hep-ph/0604178



coupling to the Higgs field in Electroweak sector
= *bare mass*

vs.

constituent mass, issued by confinement

→ static mass vs dynamic mass

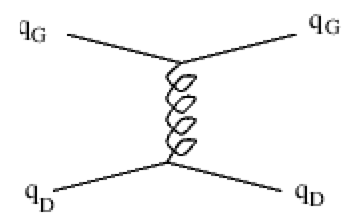
Key : *explicit* breaking of chiral symmetry in QCD

(mass = example of the fact that matter is an interleaved product of matter ... and interactions)

II.2 – Chiral symm. : breaking vs. restoration

$$\mathscr{L}_{QCD} = \ldots + m_q(\bar{\psi}_q^L \psi_q^R + \bar{\psi}_q^R \psi_q^L) + \ldots$$

- **if $m_q = 0$**, chiral symmetry preserved
  ⟶ 2 distinct world of quarks…
  Each hadron would have a chiral partner same mass, but opposite parity .
  “Left quarks stay left, right stay right”



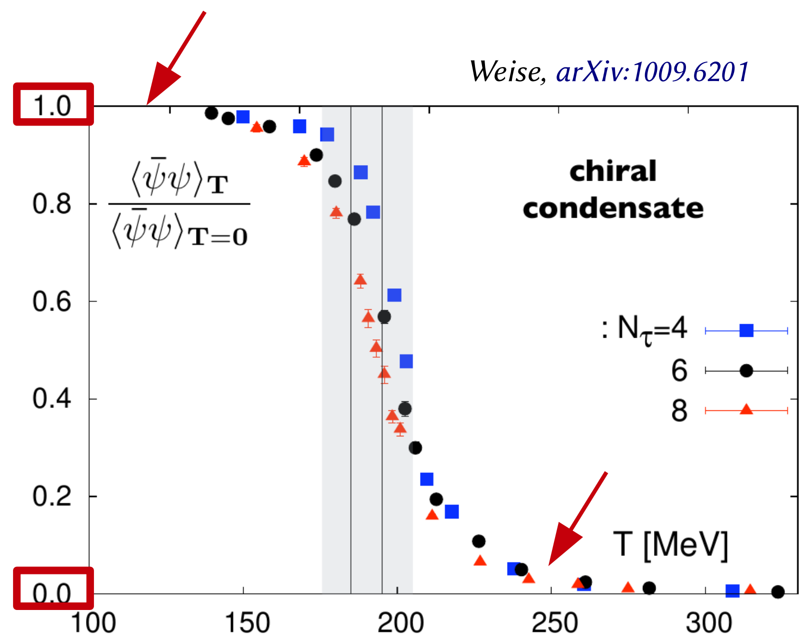
- **In fact**, *spontaneous* breaking : m_u, m_d, m_s small but ≠ 0…

  But : no existing spectrum of hadrons (any of them) observed with a partner close to it in mass

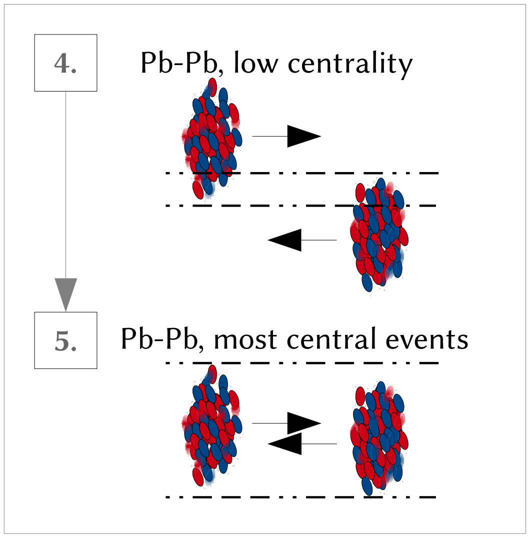
- **In fact²**, *explicit* symmetry breaking ! (*say, breaking very badly*)
  Key : QCD vacuum
  Order parameter : chiral condensate,
  vacuum expectation value $< \psi_q \psi_{\bar{q}} >$

  - $< \psi_q \psi_{\bar{q}} > \neq 0$, where chiral symm. = broken
    ⟶ non-empty vacuum !
  - $< \psi_q \psi_{\bar{q}} > = 0$, where chiral symm. = preserved
    ⟶ empty vacuum…

Weise, arXiv:1009.6201



III.1 – Evt activity : centrality in AA ?



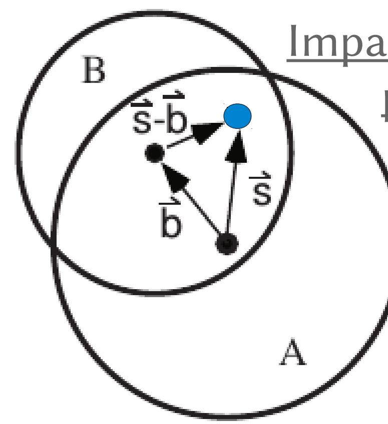
Question :

Which observable, suitable for centrality ?

Which observable for the **energy density** reached by the system ?

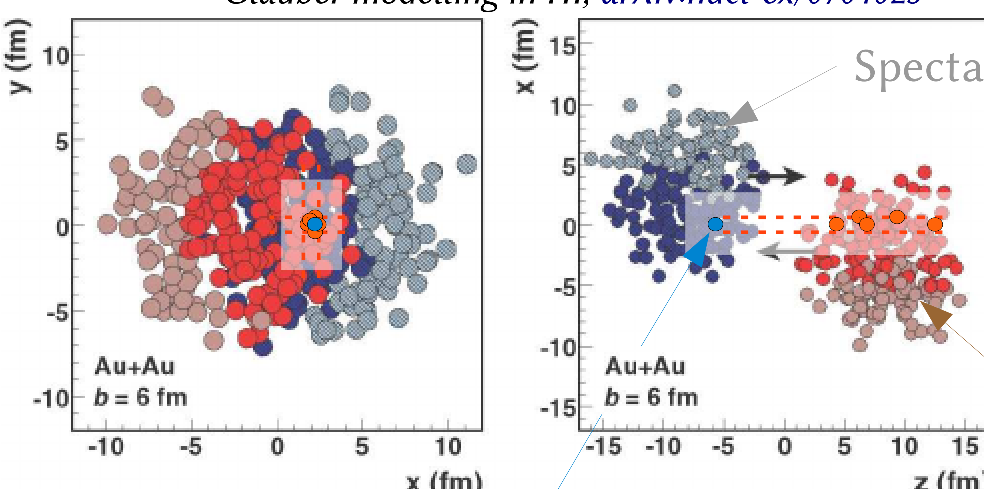
→ Usual answer :

(MC) Glauber model



Impact parameter *b* between the 2 nucleus centres

Glauber modelling in HI, arXiv:nucl-ex/0701025



Spectators

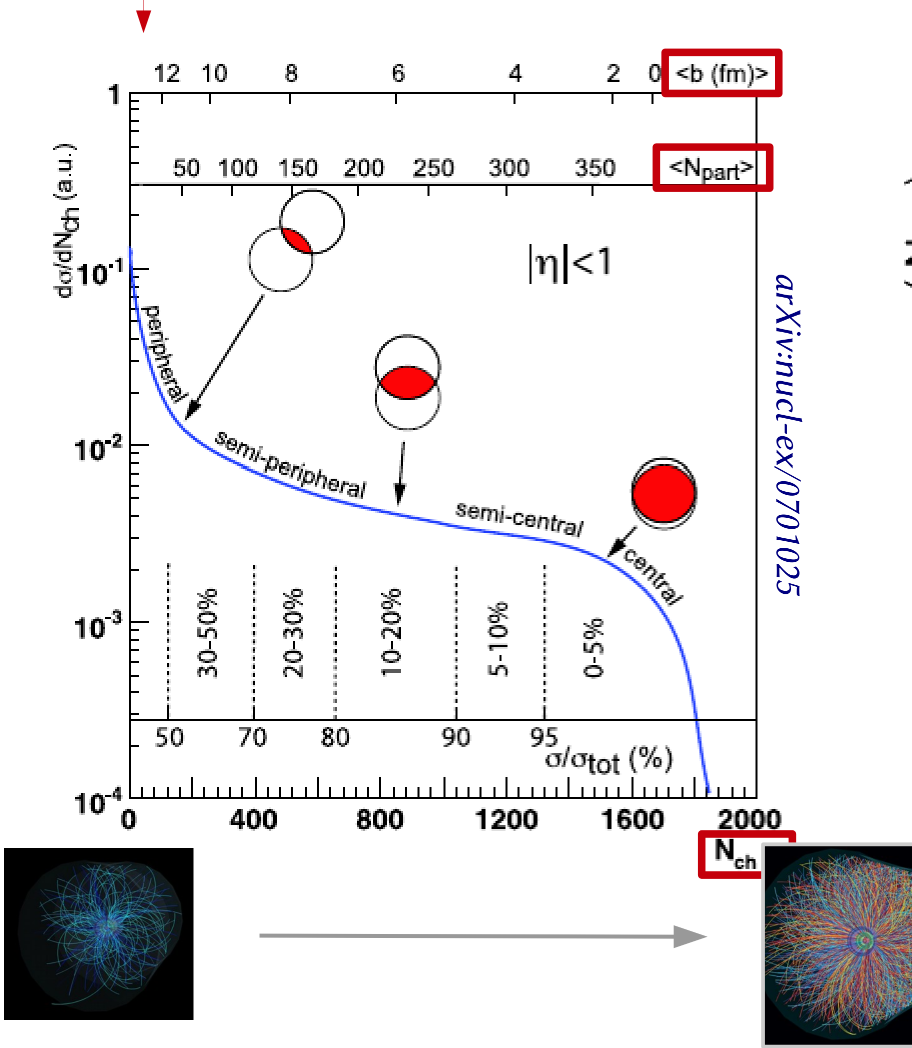
Spectators

A participant can interact several times…

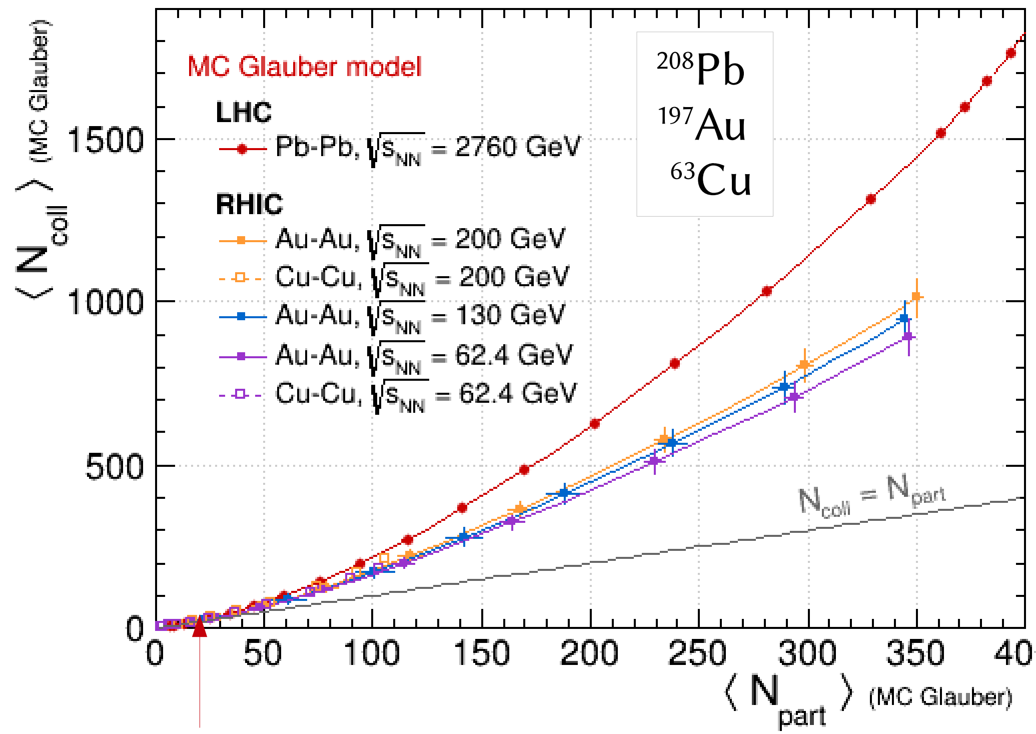
- N_{PART} = nucleons in the overlap region
- N_{COLL} = equivalent number of inelastic nucleon-nucleon collisions

III.2 – Event activity : exp^al assessm^t and output

1. Nch = f(N_{PART}) = f(centrality)



Based on data from :
Ray, J. Phys. G 35 (2008) 125106
STAR, PRC 79 (2009) 034909
ALICE, arXiv:1301.4361, Tab.1



2. N_{COLL} = f(N_{PART})

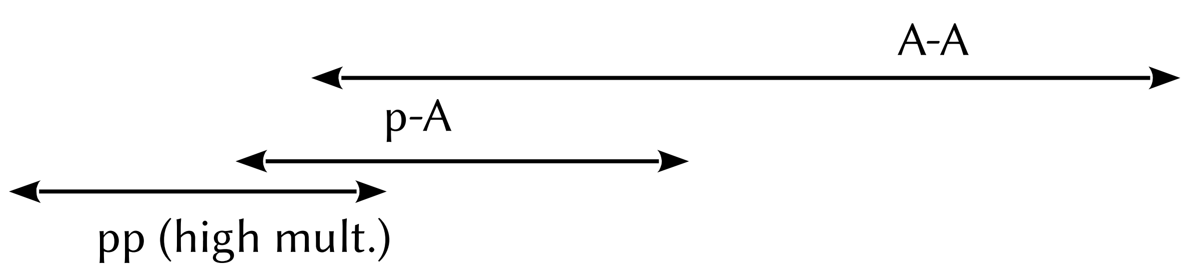
- In pp : $N_{PART} = 2$ / $N_{COLL} = 1$
- In A-A : $N_{PART} < N_{COLL}$

III.3 – Event activity : alternatives

3. But note, MC Glauber is not the only possibility ...

What's about :

- N_{PART} or N_{COLL} ?
- mix (core-corona...) ?
- $dN_{Ch}/d\eta$?
- $dN(\pi^{\pm})/dy$?
- ΣE_T ? at y ~0 ? at fwd y ?
- *nb of jets ?*
- ...



IV.1 - Strange : enhancement in QGP, original idea...

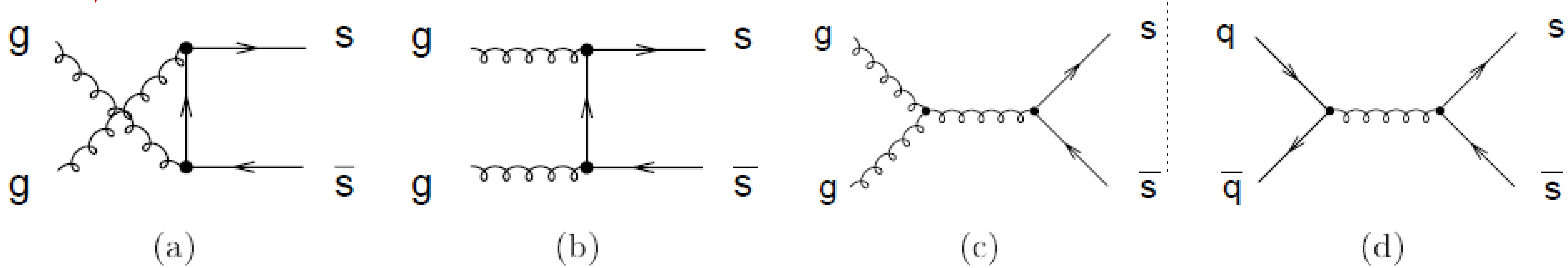
Historical signature : "*strangeness enhancement*"

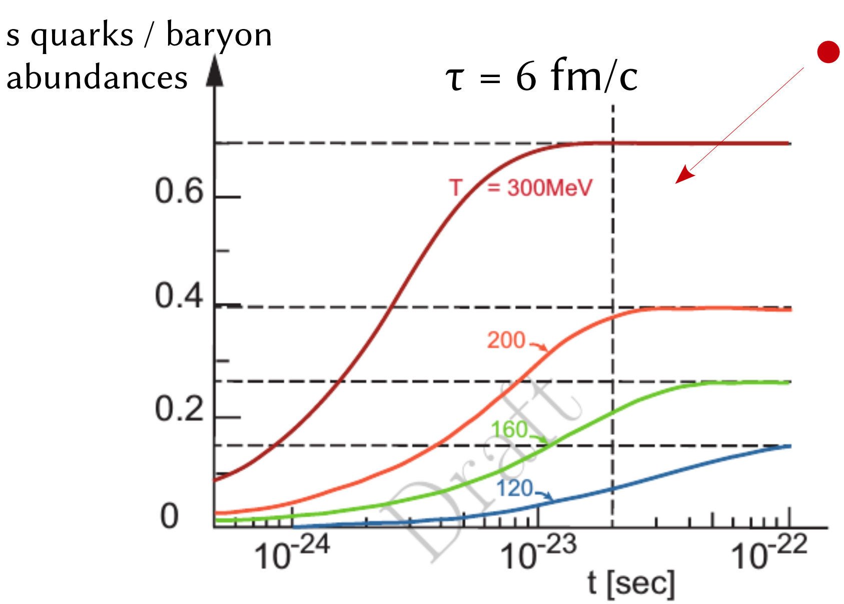
- Gluon fusion (**gg** $\longrightarrow$ **s$\bar{\text{s}}$**) made frequent in QGP

  Chiral symm. (partially) restored $\longrightarrow$ $\boldsymbol{m_s}$ **~ 100 MeV** $\longrightarrow$ $\boldsymbol{m_s < T_{QGP}}$

  = energy- and/or time-efficient...

  from *Rafelski & Müller, PRL 48 (1982) 1066 + Koch, Rafelski, Müller, Phys. Rep. 142 (1986)167-262*





- Hyp.: mass for *s* quarks + value for α_S,

  then ... equilibration expected

  (i.e. *s* quarks may be *thermalised* as *u*,*d* quarks !

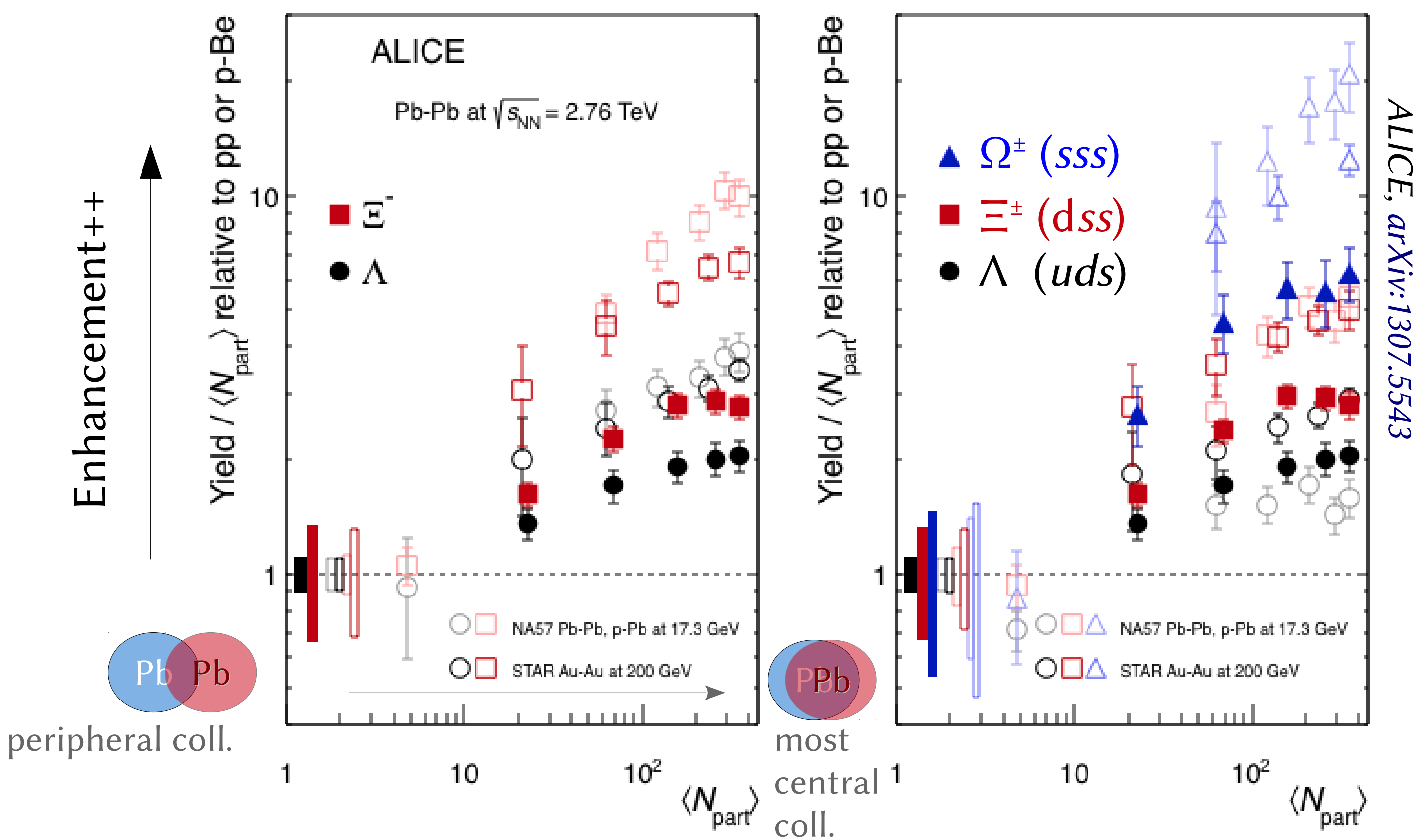
  $\longrightarrow$ *s* belong to bulk physics ...)

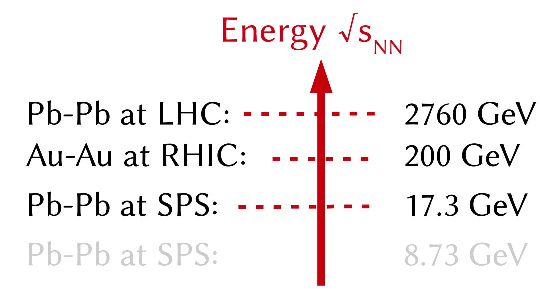
$\longrightarrow$ This "extra" population of *s* quarks

= to be reflected in the hadron population of the final state...

IV.2.a – Strangeness enhancem^{t} : overall status

at the same $\sqrt{s_{NN}}$, $$E_{AA} = \frac{(1/N_{evt}^{AA}) \; dN^{AA}/dy}{\langle N_{part} \rangle \; (1/N_{evt}^{pp}) \; dN^{pp}/dy}$$





Check out the overall trend :

$E_{AA}(\Omega, \Xi, \Lambda) > 1$ ⟶ enhancement is there !

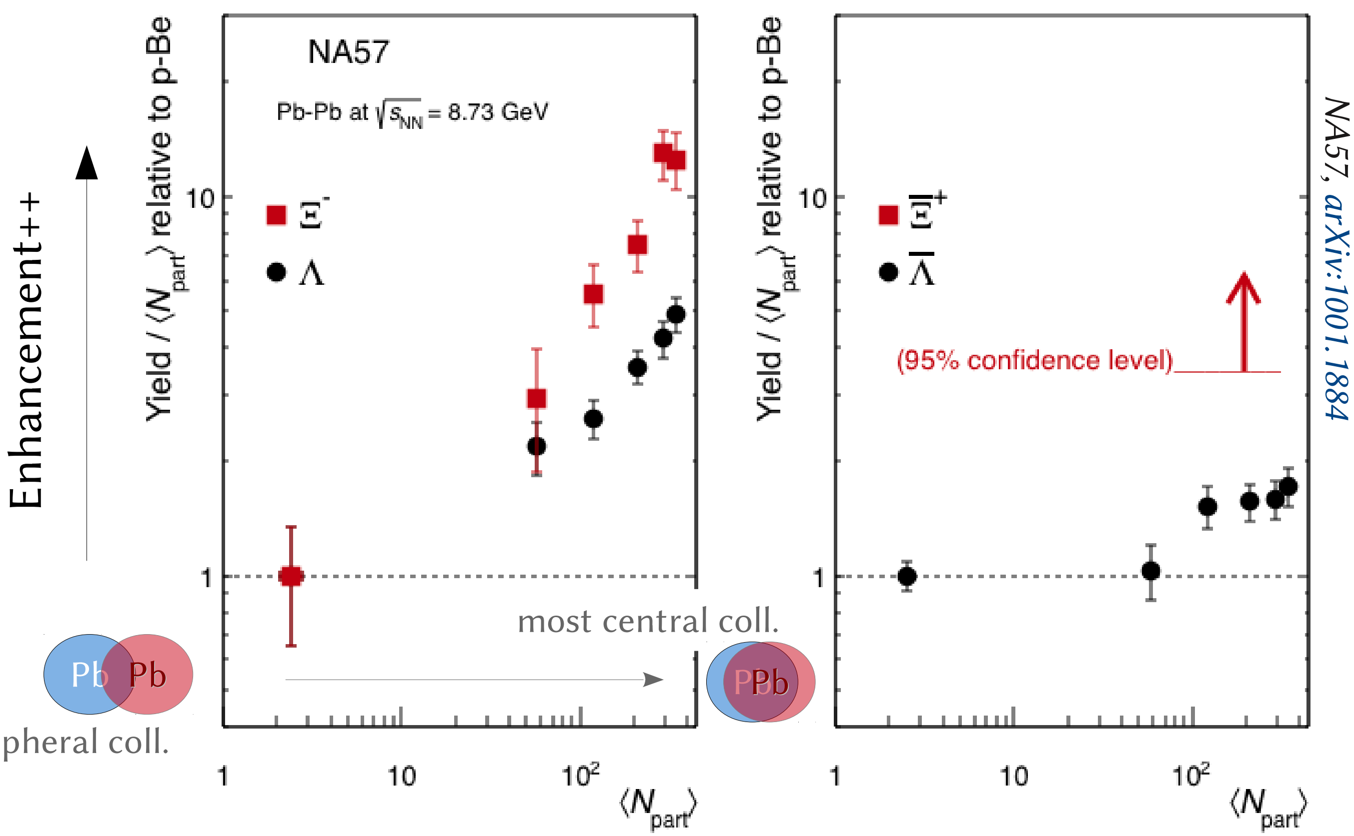
\+ species dependence (*the stranger, the more enhanced*)

\+ centrality dependence (*enhancement++ with more* N_{part})

But well... to be confessed : this plot is kind of crowded...

plots : courtesy Boris Hippolyte

IV.2.b – Strangeness enhancem^t : SPS status



Reference system : p-Be

Energy $\sqrt{s_{NN}}$

Pb-Pb at LHC: 2760 GeV

Au-Au at RHIC: 200 GeV

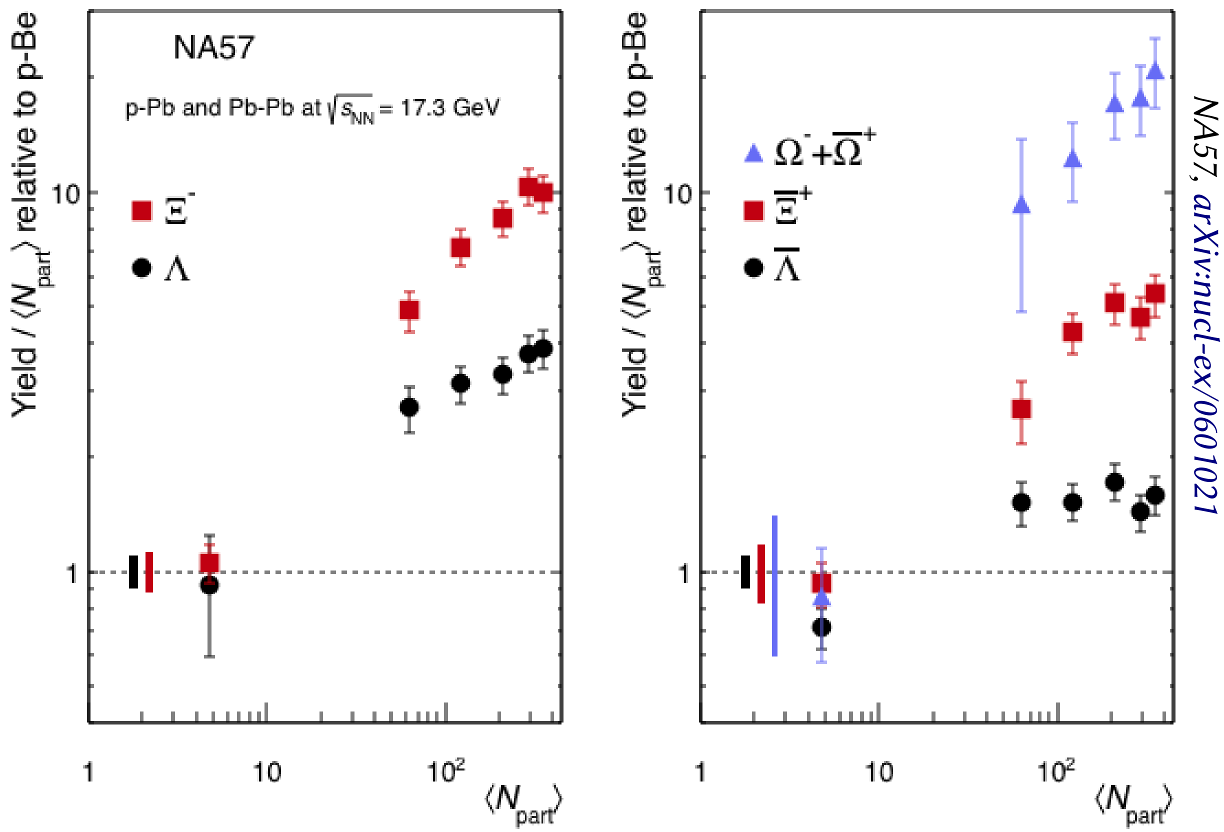
Pb-Pb at SPS: 17.3 GeV

Pb-Pb at SPS: 8.73 GeV

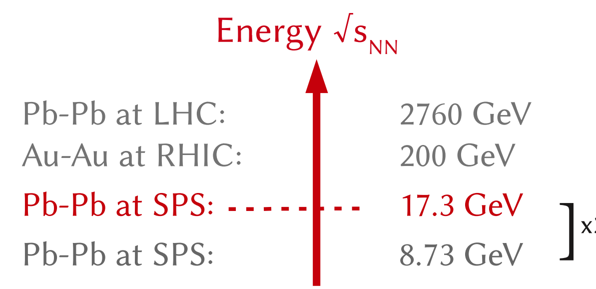
Note : - hierarchy : " $E_{AA}(\Xi) > E_{AA}(\Lambda)$ "

- centrality dependence + no saturation reached
- difference between (Λ, $\overline{\Lambda}$) (baryon nb conservation)

IV.2.c – Strangeness enhancem^{t} : top-SPS status



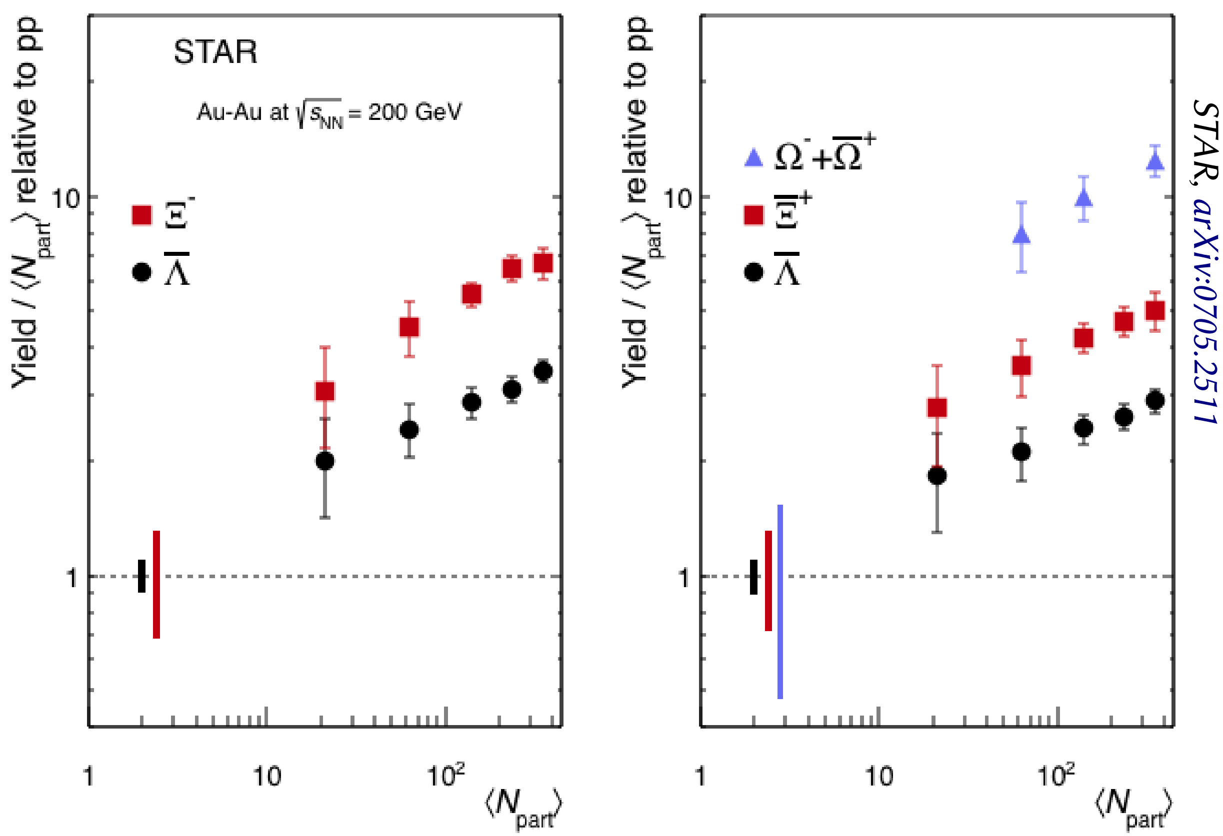
Reference system : p-Be (p-Pb)



Note :
- hierarchy : " $E_{AA}(\Omega) > E_{AA}(\Xi) > E_{AA}(\Lambda)$ "
- centrality dependence + no saturation ~reached
- difference between $(\Lambda, \overline{\Lambda})$, $(\Xi, \overline{\Xi})$ (baryon nb conservation)
- $E_{AA}(\Omega) \leq \sim 20$!

cf. CERN com° (2000, QGP at SPS)

IV.2.d – Strangeness enhancem^t : RHIC status



Reference system : pp

Energy $\sqrt{s_{NN}}$

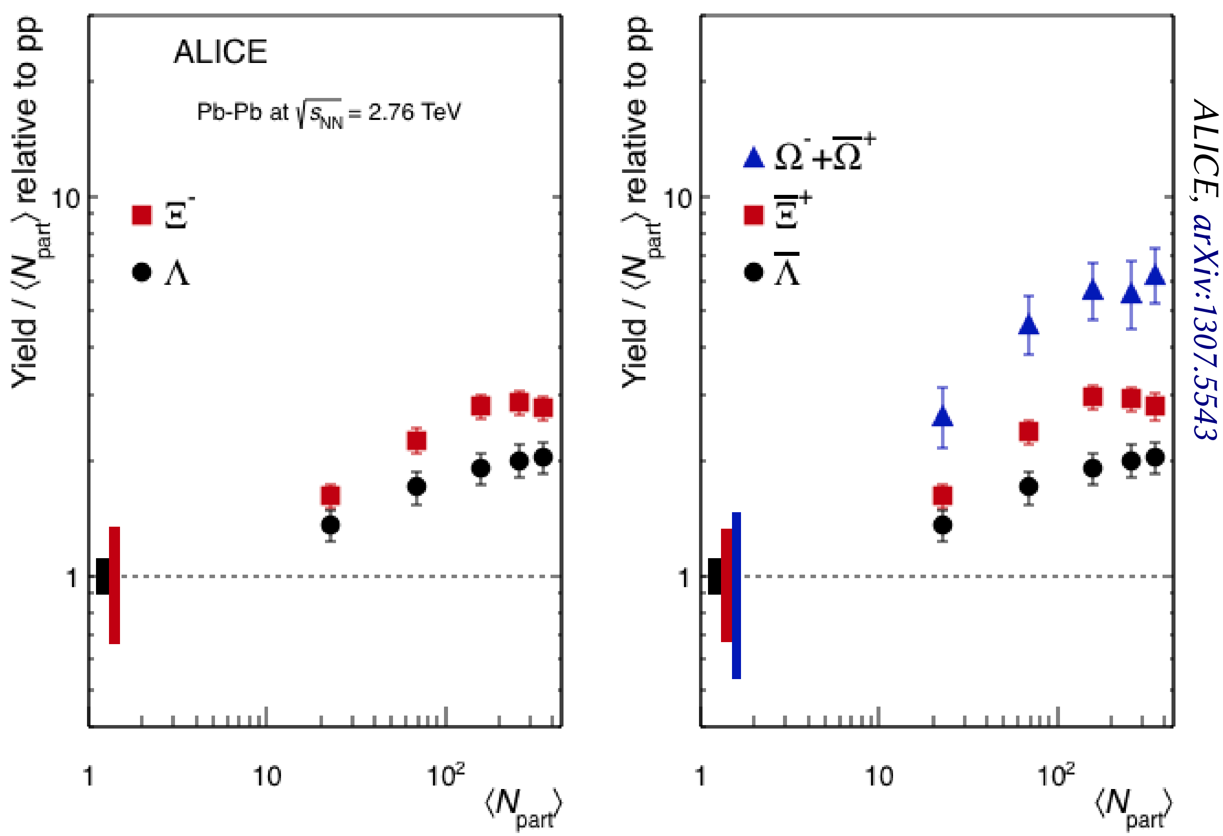
Pb-Pb at LHC:	2760 GeV
Au-Au at RHIC:	200 GeV
Pb-Pb at SPS:	17.3 GeV
Pb-Pb at SPS:	8.73 GeV

x12

Note :
- hierarchy : " $E_{AA}(\Omega) > E_{AA}(\Xi) > E_{AA}(\Lambda)$ "
- centrality dependence + no saturation reached
- difference between (Λ, $\bar{\Lambda}$), (Ξ, $\bar{\Xi}$) (baryon nb conservation) but now reduced !
- $E_{AA}(\Omega) \leq \sim 15$ … i.e. $E_{AA}(\Omega)^{[RHIC]} < E_{AA}(\Omega)^{[top\ SPS]}$ while $\sqrt{s_{NN}}$ x12 ?!

plots : courtesy Boris Hippolyte

IV.2.e – Strangeness enhancem^{t} : LHC status



<u>Reference system :</u> pp

interpolation at √s = 2.76 TeV
(between 0.2, 0.9 and 7 TeV)

Energy $\sqrt{s_{NN}}$

Pb-Pb at LHC:	2760 GeV
Au-Au at RHIC:	200 GeV
Pb-Pb at SPS:	17.3 GeV
Pb-Pb at SPS:	8.73 GeV

x14
x160

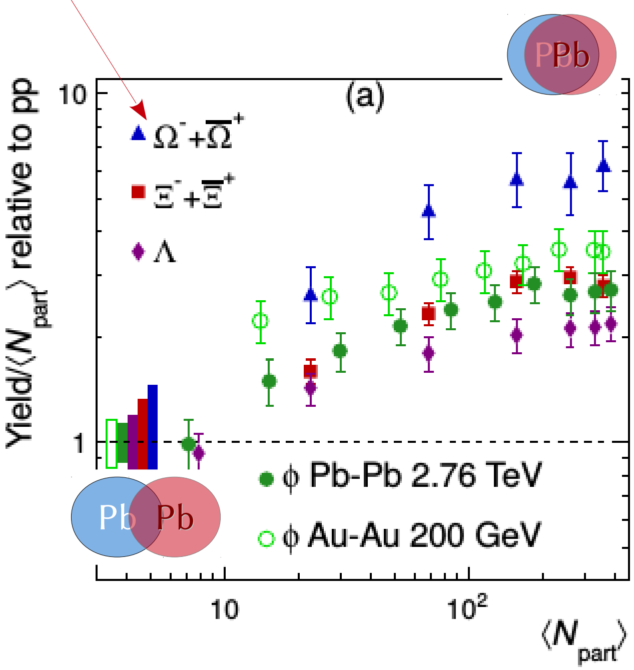
Note :
- hierarchy : " $E_{AA}(\Omega) > E_{AA}(\Xi) > E_{AA}(\Lambda)$ "
- centrality dependence + saturation ~reached ?
- ~no difference between $(\Lambda, \overline{\Lambda})$, $(\Xi, \overline{\Xi})$
- $E_{AA}(\Omega) \leq \sim 6$ … i.e. $E_{AA}(\Omega)^{[LHC]} < E_{AA}(\Omega)^{[RHIC]} < E_{AA}(\Omega)^{[top\ SPS]}$ while ($\sqrt{s_{NN}}$ x12) x14 ?!

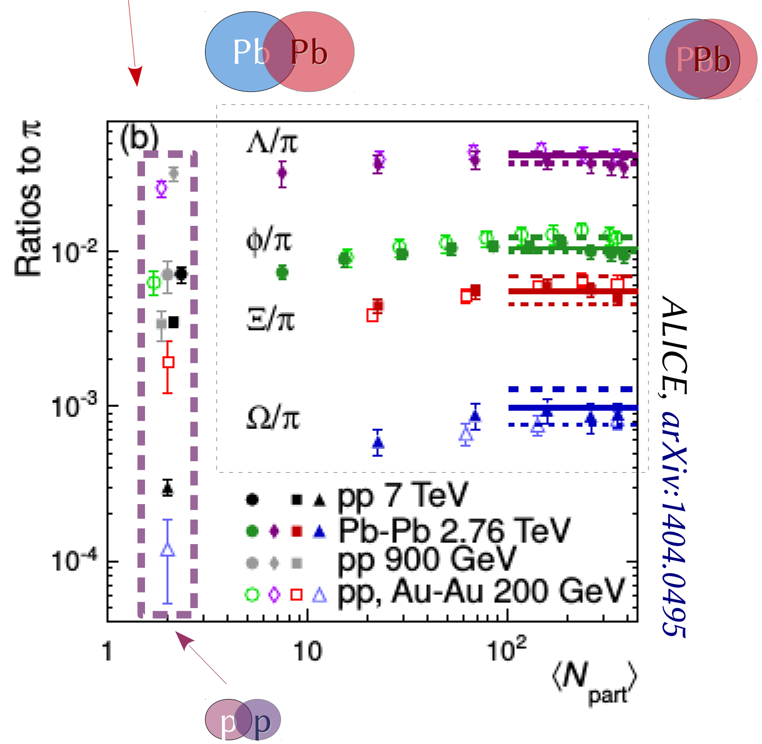
IV.3 – Strangeness enhancem^t : another look

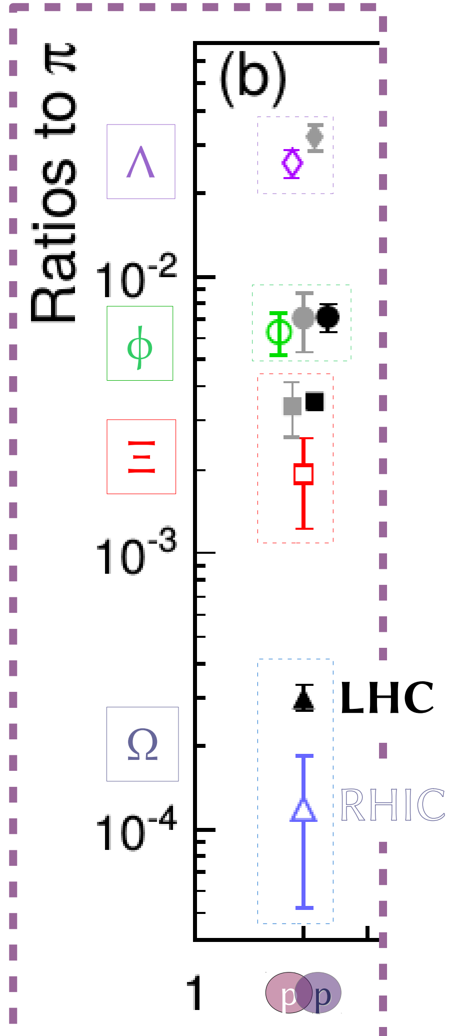
at the same $\sqrt{s_{NN}}$,

1. $E_{AA} = \dfrac{(1/N^{AA}_{evt})\ dN^{AA}_X/dy}{\langle N_{part}\rangle\ (1/N^{pp}_{evt})\ dN^{pp}_X/dy}$

2. $X/\pi = \dfrac{dN^{system}_{(X)}/dy}{dN^{system}_{(\pi)}/dy}$ *(for a given system)*







$E_{AA}(\Omega)^{[LHC]} < E_{AA}(\Omega)^{[RHIC]} < E_{AA}(\Omega)^{[top\ SPS]}$

→ increase of the pp-baseline production with $\sqrt{s}$!

IV.4 – Strangeness enhancem^{t} : some subtleties…

Strangeness Enhancement = complex phenomenon, leading to long-standing debates
Still… it *IS* a valid concept !

Some further qualifications needed, though…

<u>ex. :</u> ***a.*** Normalisation to pp, pA
(N_{COLL}, N_{PART}, sthg else ?)

b. Centrality dependence
(unlike prediction, no saturation of the enhancement with centrality…)

⟶ favour the *idea of core-corona* mixture in the collision system
- core = QGP place
- corona = superposition of independent nucleon-nucleon collisions

c. "*Canonical suppression*"
(++ easier to produce strange baryons with increasing $\sqrt{s}$)

d. $\sqrt{s_{NN}}$ dependence of the enhancement
(decreased enhancement with increasing $\sqrt{s_{NN}}$?!)

⟶ evolution of the *pp baseline* with collision energy

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V.1.a – Method : setting the experimental stage…

Basis :

Inelastic production (~Min Bias) = f(p_T), in pp 7 TeV

2. - detector PID techniques (dE/dx, TOF, relat. dE/dx)

2. - inv. mass with 1^{ry}-like tracks +PID

2. - inv. mass with 2^{ndry} tracks (+PID)

1. - rapidity range of interest

In concrete terms :

$1/N_{evt}(\mathrm{INEL}).\ d^2N(\pi^{\pm}, K^{\pm}, p, \bar{p}, K^*(892), \phi(1020), \ldots, K^0_S, \Lambda, \bar{\Lambda}, \Xi^-, \bar{\Xi}^+, \Omega^-, \bar{\Omega}^+)/dp_T dy \mid y{\sim}0 = f(p_T)$

for inelastic collisions

NOTE :

dN_{ch}/dy in INEL pp 7 TeV at y~0 ≈ **5-6 particles/evt**

Relative fraction in population H / Σ_i [prompt π, K, p]

$\pi^{\pm}$	$K^{\pm}$	p	K^0_S	$K^*(892)$	$\phi(1020)$	Λ	$\Xi^{\pm}$	$\Omega^{\pm}$
~ 84.5%	~ 10.7%	~ 4.7%	~ 5%	~ 1.8%	~ 0.6%	~ 3%	~ 3 ‰	~ 0.25 ‰

Ref. chosen : sum =100%

NB : fractions = here, integrated in p_T, but = f(p_T, y) !

V.1.b – Method : setting the experimental stage…

Goal :

more differential studies ⟶ "*prod° = f(p_T, multiplicity)*" in pp 7 TeV

2. - detector PID techniques (dE/dx, TOF, relat. dE/dx)

2. - inv. mass with 2ndry tracks (+PID)

1. - rapidity range of interest

In concrete terms :

$$1/\ N_{evt}(\mathrm{Ac}[i]).\ d^2N(\pi^{\pm}, K^{\pm}, p, \bar{p}, K^*(892), \phi(1020), \ldots, K^0s, \Lambda, \bar{\Lambda}, \Xi^-, \bar{\Xi}^+, \Omega^-, \Omega^+)/dp_T dy \mid y{\sim}0 = f(p_T)$$

for a given interval of event activity **Ac[i]**

Some possible estimator options :

- N_{PART} or N_{COLL} ?
- mix (core-corona…) ?
- N_{ch}(raw) ?
- $dN_{Ch}/d\eta$? ⟶ at η ~0 ? at fwd η ?
- $dN(\pi^{\pm})/dy$ at y ~0 ?
- ΣE_T at η ~0 ?
- *nb of jets ?*
- *combination of …*
- …

(If things ~ equivalent 2 by 2 in AA,
Note this is not the case in pp)

3. Issues :

a) global event class ?
i.e. what will stand for the sample "0-100%" …

b) which definition of the event activity ?
i.e. what one will hash % by % …

V.1.c – Method : setting the experimental stage…

Goal :

more differential studies ⟶ "*prod° = f(p_T, multiplicity)*" in pp 7 TeV

2. - detector PID techniques (dE/dx, TOF, relat. dE/dx)

2. - inv. mass with 2[ndry] tracks (+PID)

1. - rapidity range of interest

In concrete terms :

$1/N_{evt}(Ac[i]).\, d^2N(\pi^{\pm}, K^{\pm}, p, \bar{p}, K^*(892), \phi(1020), \ldots, K^0_S, \Lambda, \bar{\Lambda}, \Xi^-, \bar{\Xi}^+, \Omega^-, \Omega^+)/dp_T dy \mid y{\sim}0 = f(p_T)$

for a given interval of event activity Ac[i]

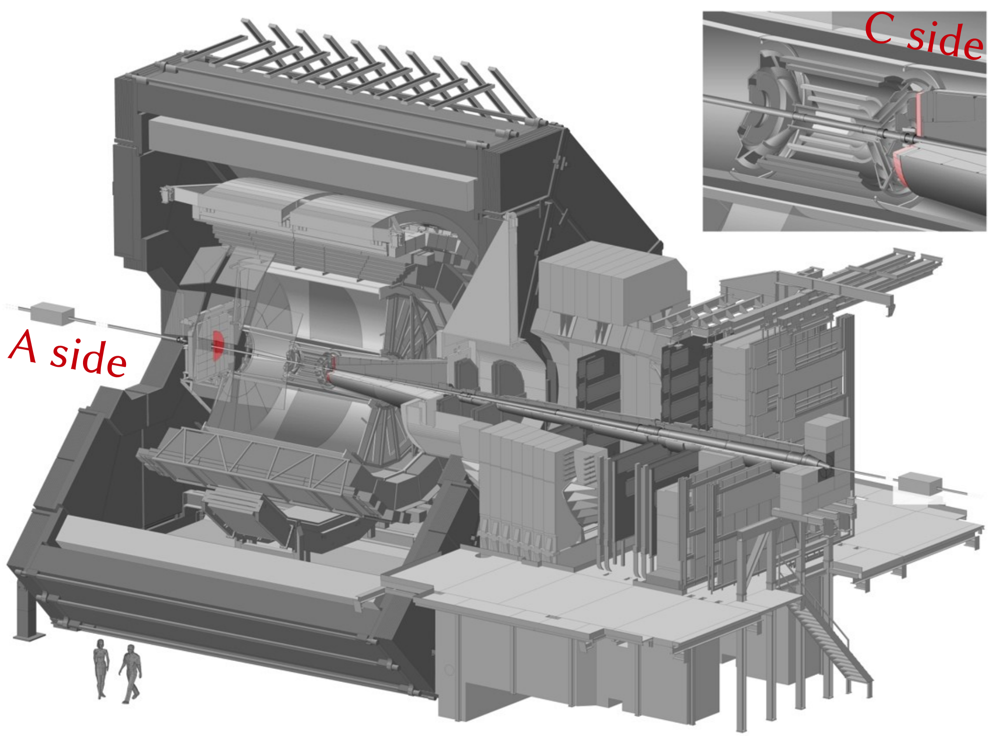
4. Event normalisation

= how many events in my $[a_1\text{-}a_2]$ % interval ?

⟶ raise the question of the inefficiencies in the event selection… Is it free of bias for each species ?

e.g. you want to study (Ω^- = 3 secondary tracks),
or (K^* = 2 primary-like tracks)
in an event class being N_{Ch} = [1-3] …

V.2 – Method : ALICE sub-detectors used



- **Inner Tracking System = ITS**

$|\eta_{ITS}| < 0.9$ / $p_T^{threshold} \sim 50$ MeV/c

2 layers = silicon pixels, SPD
2 layers = silicon drift, SDD
2 layers = silicon strips, SSD

⟶ trigger, vertexing, tracking + PID (dE/dx)

- **Time Projection Chamber = TPC**

$|\eta_{TPC}| < 0.9$ / $p_T^{threshold} \sim 150$ MeV/c

$Ne/CO_2/N_2$ (run I) gas as active volume

⟶ tracking + PID (dE/dx)

(• + Time of Flight = TOF)

$|\eta_{TOF}| < 0.9$ / / $p_T^{threshold} \sim 300$ MeV/c

Multiple Resistive Plate Chamber

⟶ PID (TOF...)

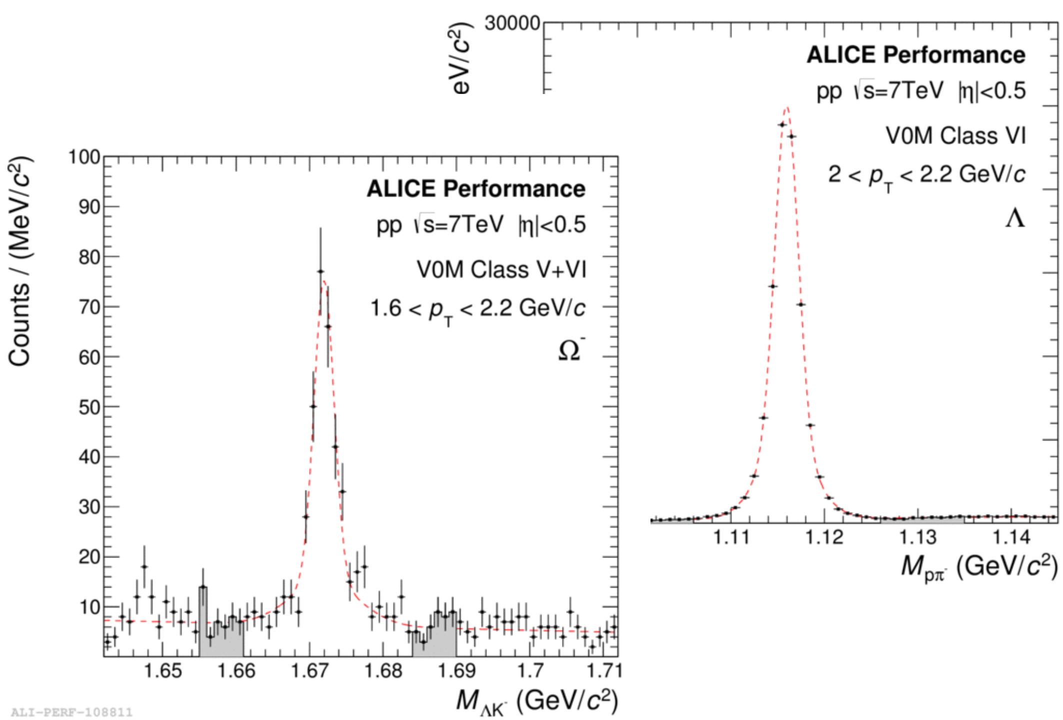
- **VZERO or V0**

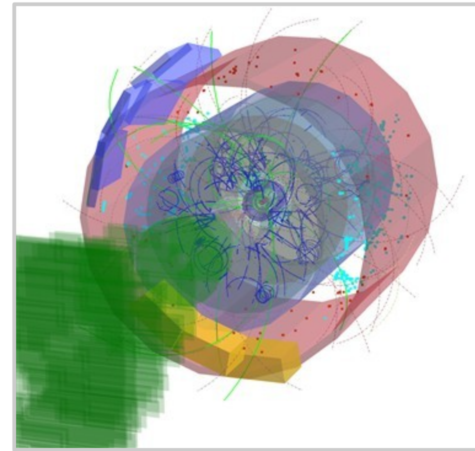
V0A = $2.8 < \eta < 5.1$
V0C = $-3.7 < \eta < -1.7$

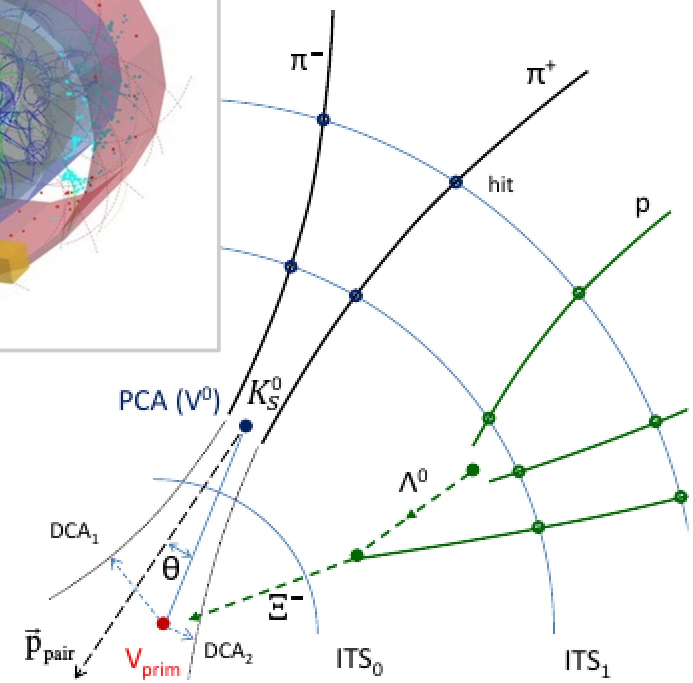
Forward arrays of scintillators

⟶ MB trigger, beam gas rejection, event activity estimator

V.2 – Method : topological reconstruction







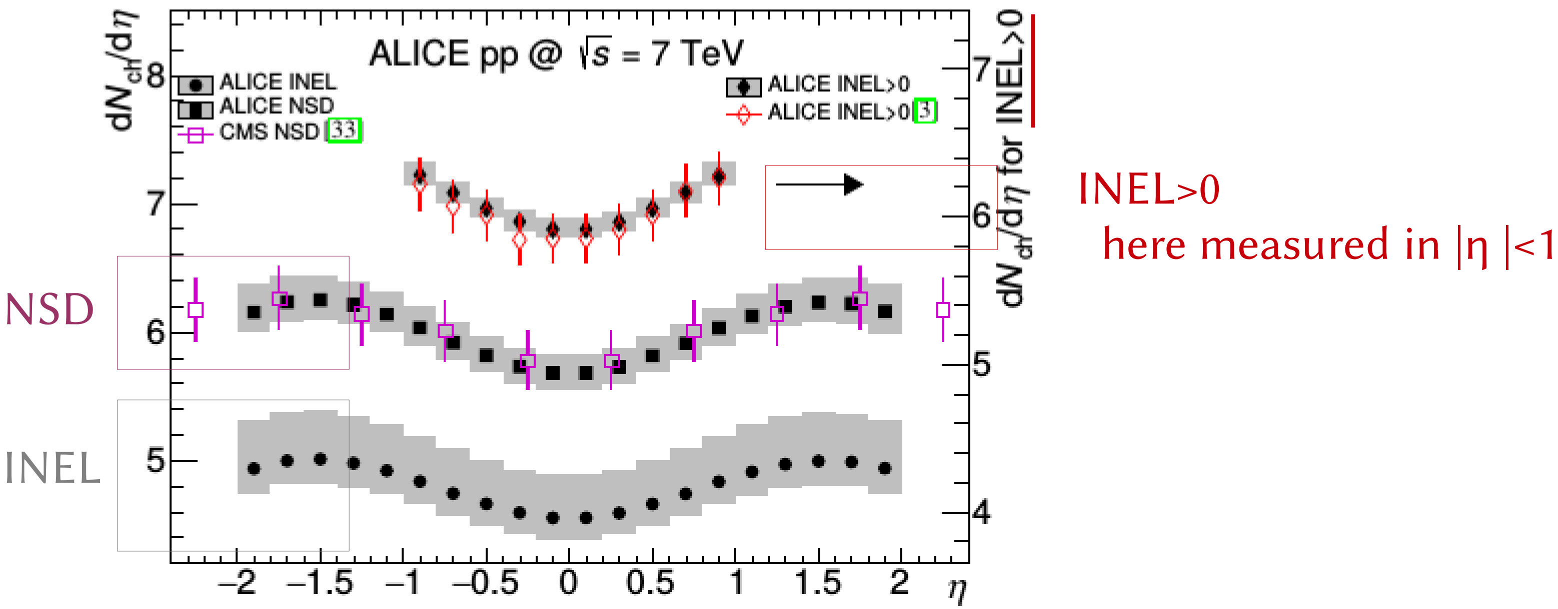
Particle	Mass (GeV/c²)	cτ (cm)	Decay channel	B.R.
K^0s (*ds*)	0.497	2.68	K^0s ⟶ $\pi^+ \pi^-$	69.2%
Λ (*uds*)	1.115	7.89	Λ ⟶ p π^-	63.9%
Ξ^- (dss)	1.321	4.91	Ξ^- ⟶ π^- (Λ⟶pπ^-)	99.9% x 63.9% = 63.8%
Ω^- (*sss*)	1.672	2.46	Ω^- ⟶ K^- (Λ⟶pπ^-)	67.8% x 63.9% = 43.3%

V.3.a – Method : global event class, 0-100%

Possible choices :

- Non-Single diffractive collision sample ?
- Inelastic collision sample ?
- INEL>0 = at least 1 charged track in |η| < 1 ?
- ...

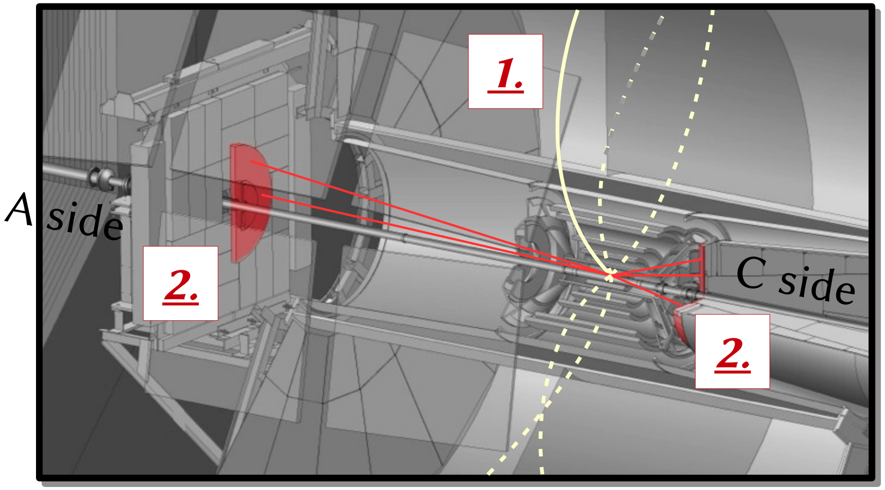
ALICE, arXiv:1509.07541



Here, choice of the class 0-100% : INEL>0 | $_{|\eta| < 0.5}$

⟶ <u>purpose</u> : minimising the model dependence

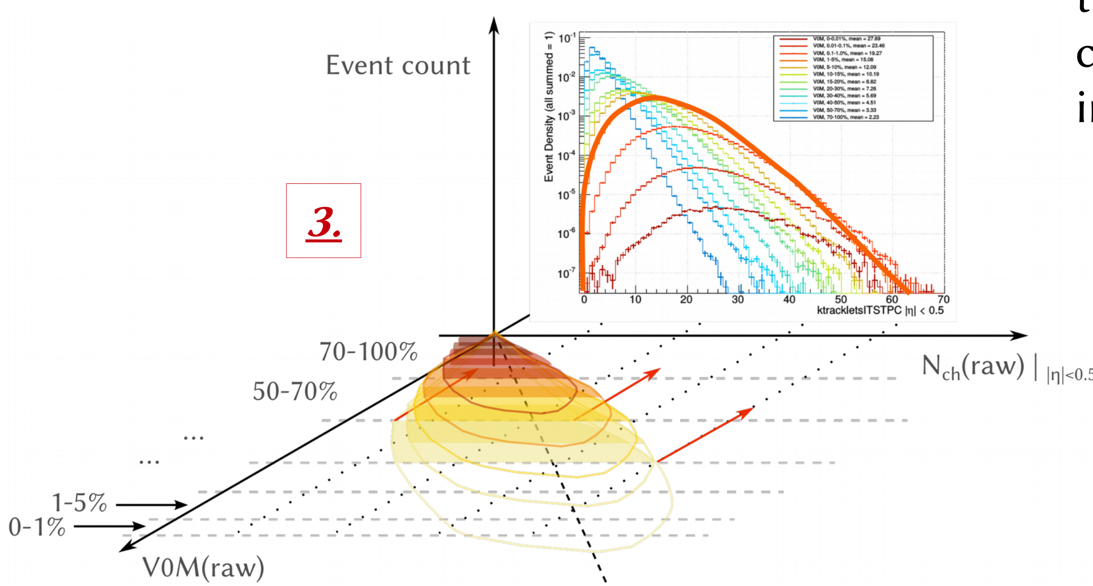
V.3.b – Method : event activity sampling

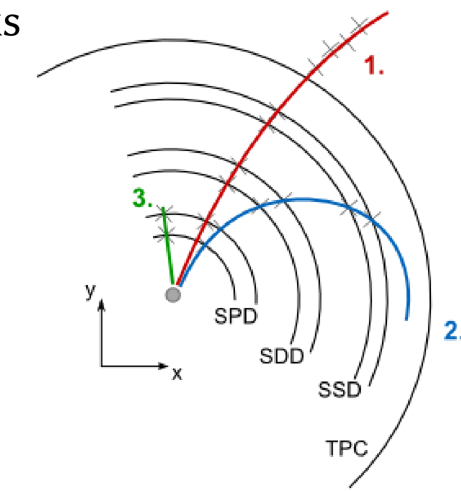


1. For events with at least 1 ch. particle in $|\eta| < 0.5$
= INEL>0 $|_{|\eta| < 0.5}$

2. sample the event activity with forward det. :
V0 suM
i.e. plain addition of V0A and V0C signals
→ V0M distrib° hashed into percentiles

3. For each V0M activity interval,
derive the mean, $\langle dN_{ch}/d\eta \rangle$, of
the *corrected* distrib° of
charged tracks
in $|\eta| < 0.5$





Antonin.MAIRE@cern.ch – Séminaire IPHC

V.3.c – Method : V0M-sampled $\langle dN_{ch}/d\eta \rangle \mid_{|\eta|<0.5}$

ALICE Nature Phys. = arXiv-1606.07424

≈ **3.5** $\langle dN_{ch}/d\eta \rangle_{INEL>0}$

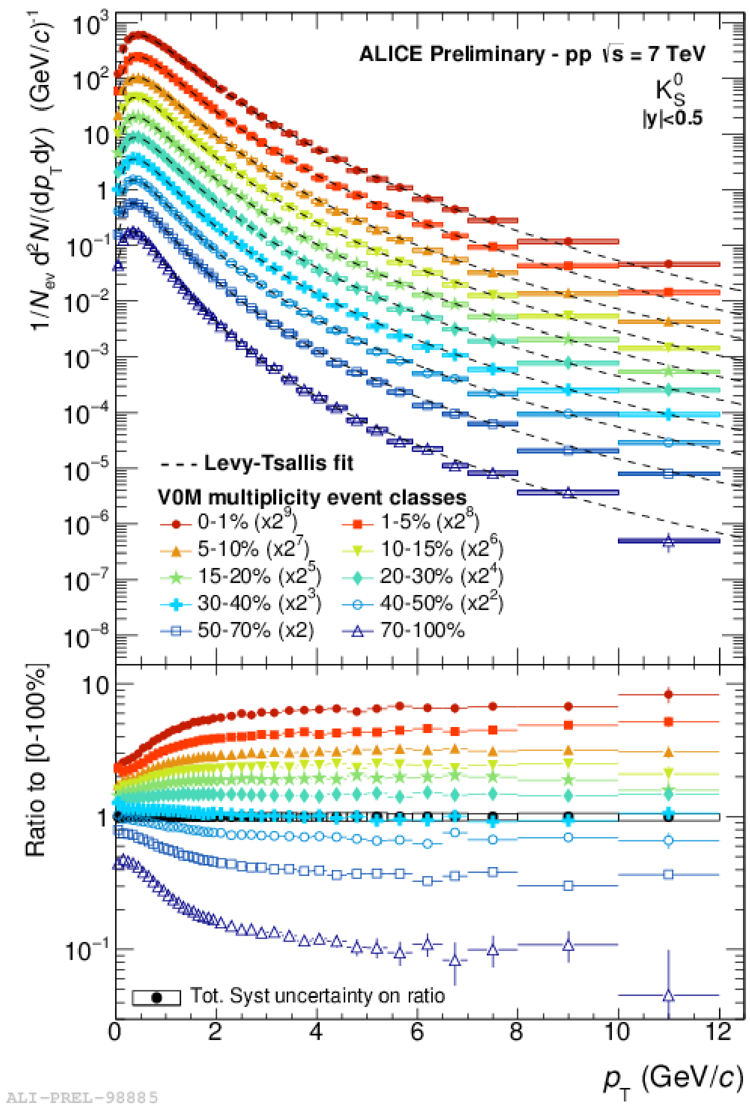
Class name	I	II	III	IV	V
$\sigma/\sigma_{INEL>0}$	0–0.95%	0.95–4.7%	4.7–9.5%	9.5–14%	14–19%
$\langle dN_{ch}/d\eta \rangle$	21.3±0.6	16.5±0.5	13.5±0.4	11.5±0.3	10.1±0.3

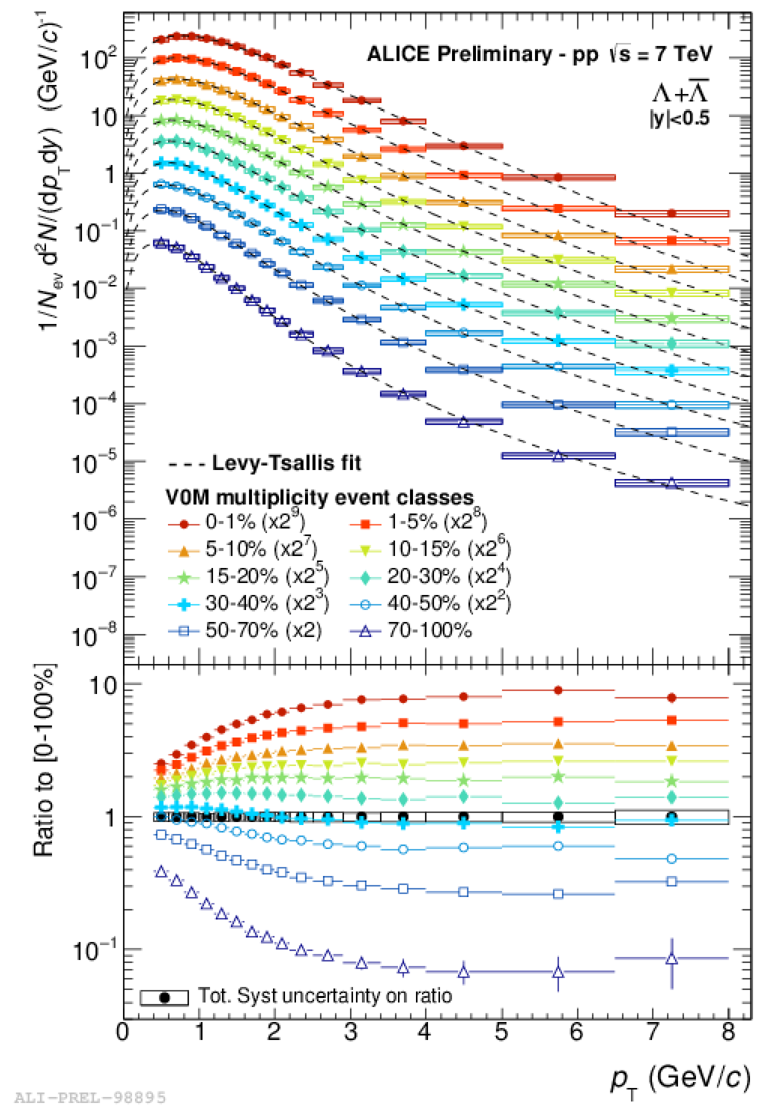
VI	VII	VIII	IX	X
19–28%	28–38%	38–48%	48–68%	68–100%
8.45±0.25	6.72±0.21	5.40±0.17	3.90±0.14	2.26±0.12

≈ **0.4** $\langle dN_{ch}/d\eta \rangle_{INEL>0}$

Reference : $\langle dN_{ch}/d\eta \rangle_{INEL>0} \approx 5.96 \pm 0.23$

VI.1 – Results : $d^2N/dp_T dy = f(p_T, \text{mult.})$ for K^0s, Λ



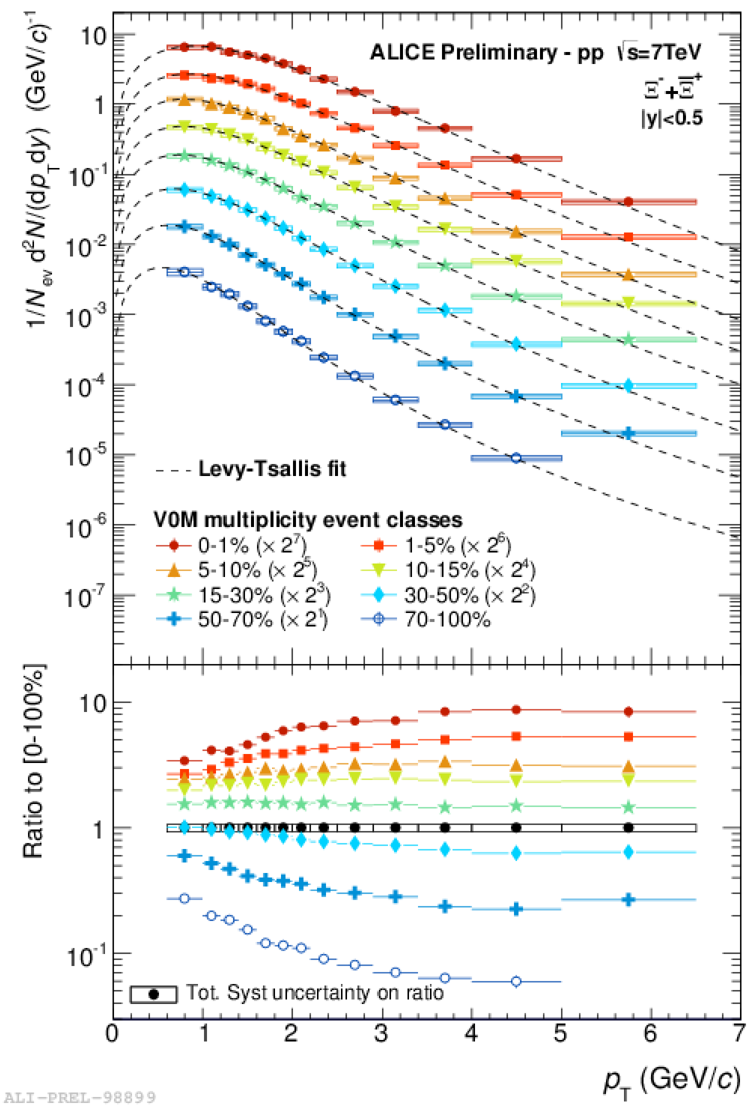


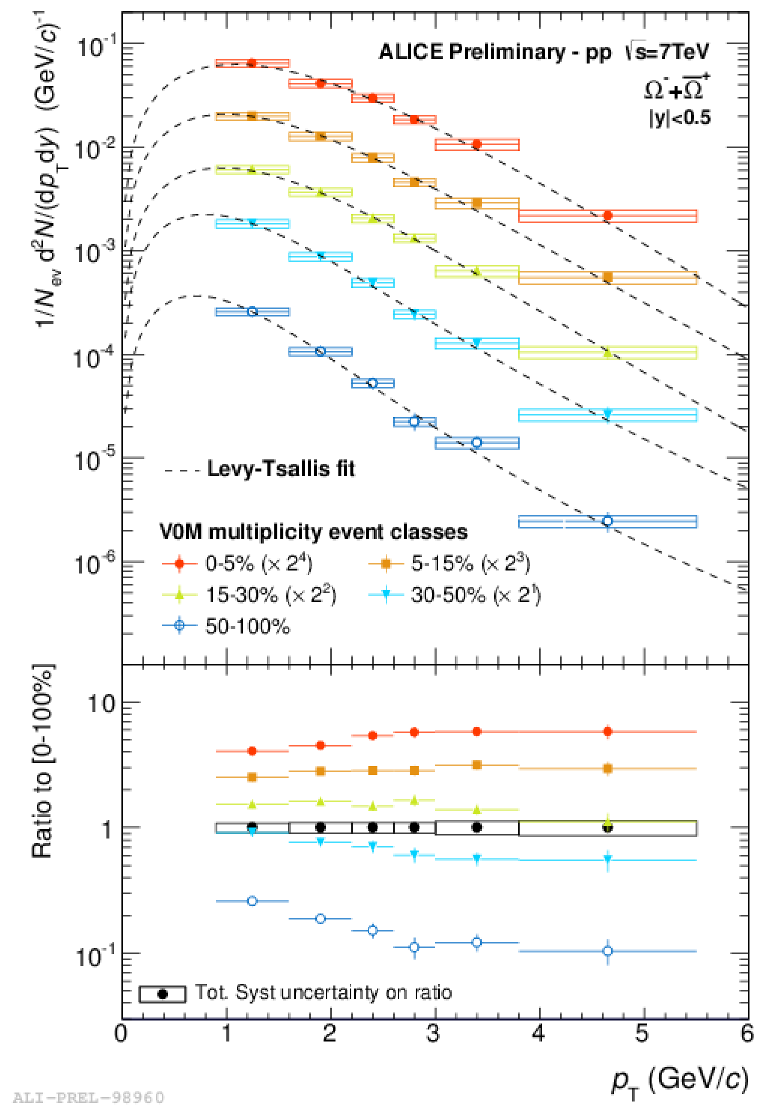
1. "Hardening" of the spectra with higher multiplicity

2. Ratio spectrum(Ac[i]) to spectrum(0-100%) ~ constant, after p_T > 3 GeV/c

3. Lévy-Tsallis fits, to get the low-p_T extrapolation → extraction of the total yield, dN/dy for each mult. interval, Ac[i]

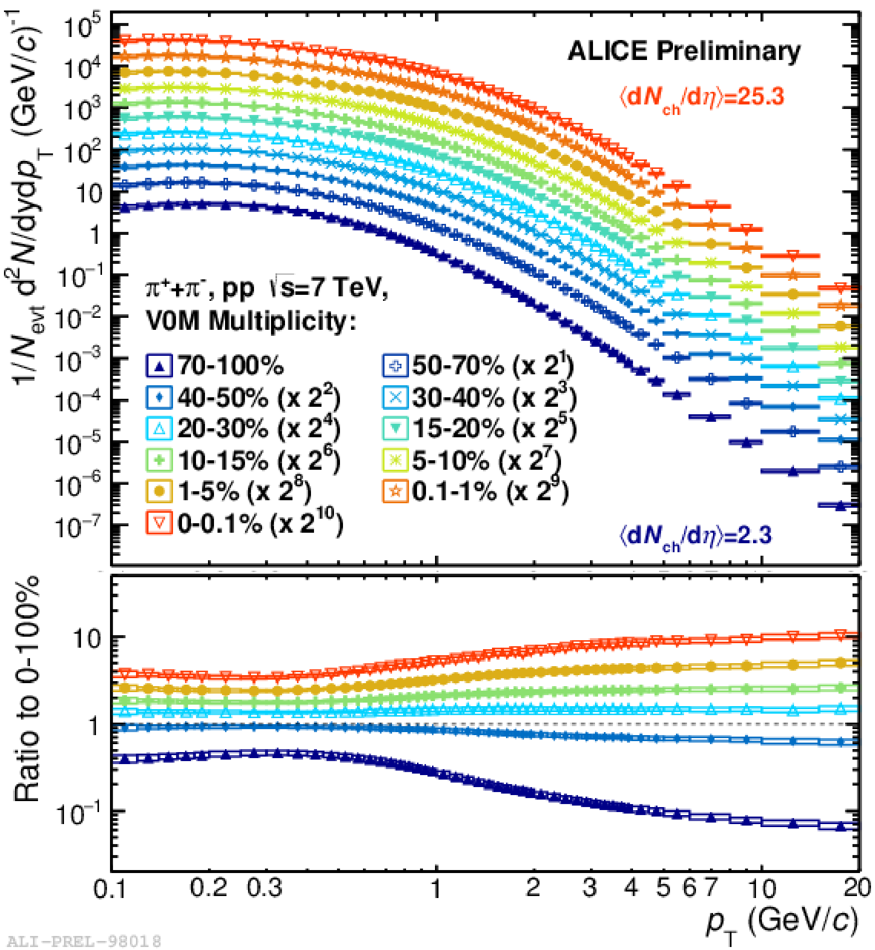
VI.2 – Results : $d^2N/dp_Tdy = f(p_T, \text{mult.})$ for $\Xi^{\mp}$, $\Omega^{\mp}$

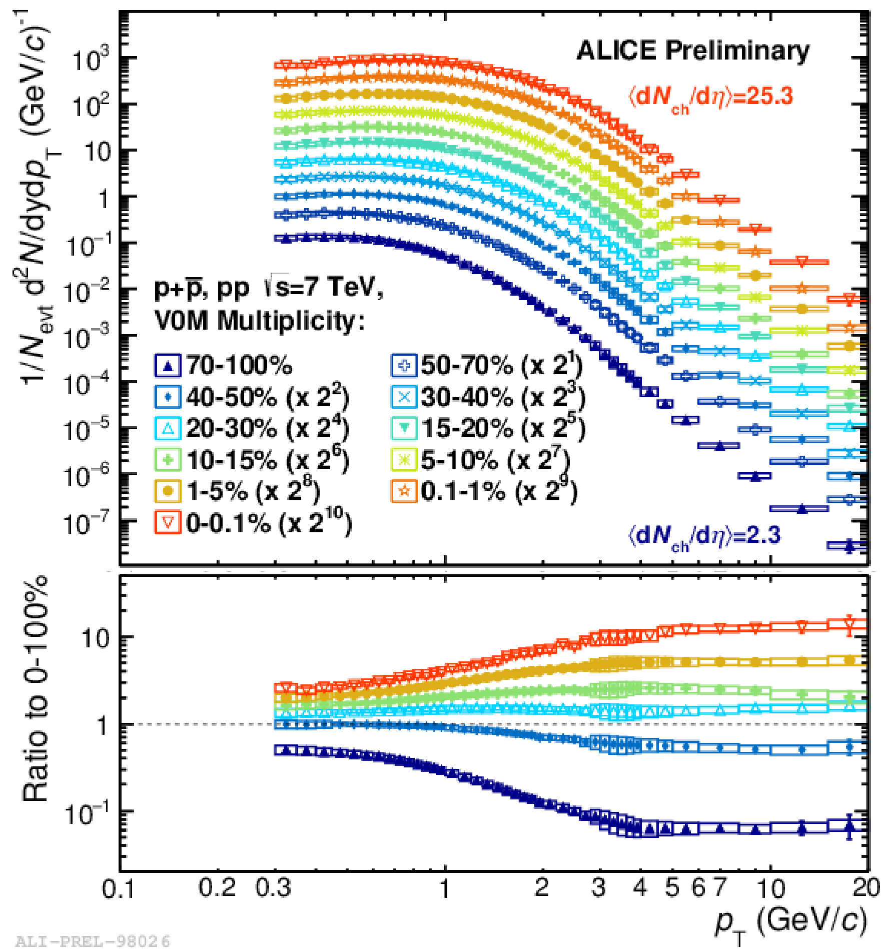




Same remarks as for K^0s and Λ
→ 1, 2, 3…

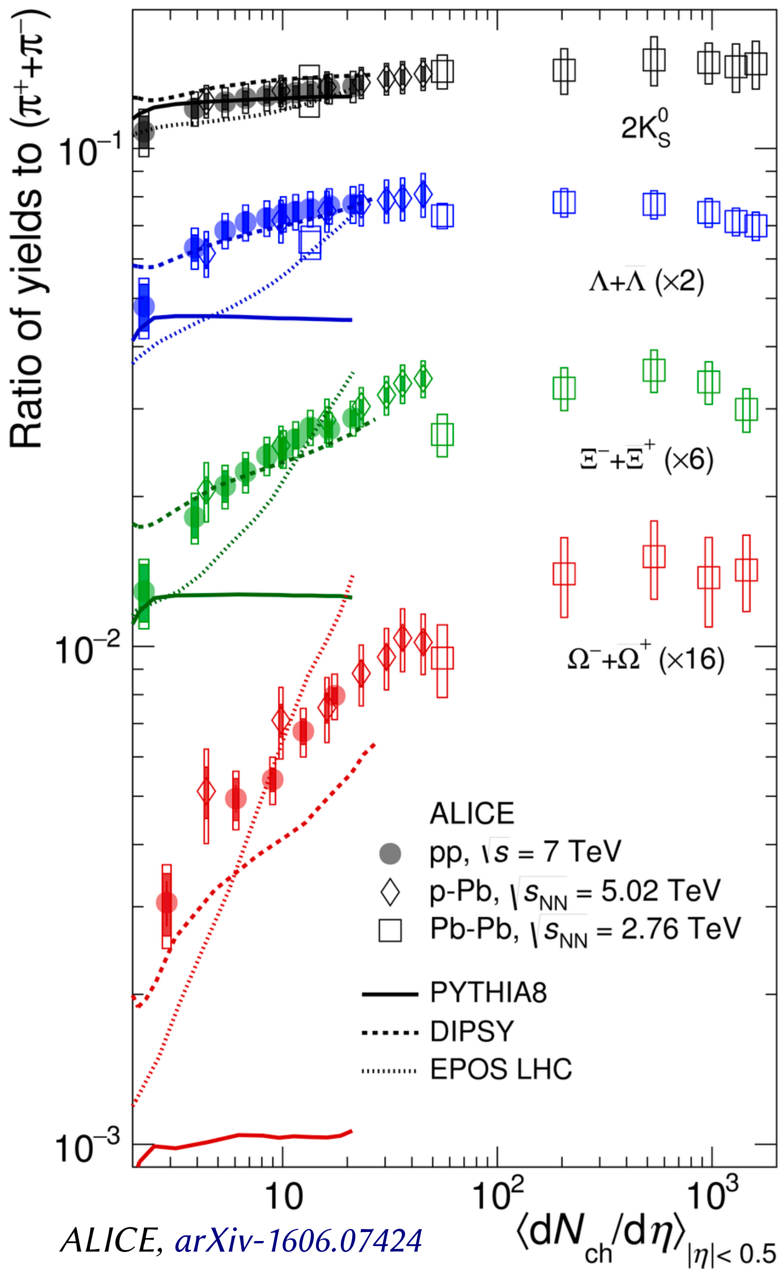
VI.3 – Results : $d^2N/dp_T dy = f(p_T, \text{mult.})$ for $\pi^\pm$, p





- p_T range = [0.1, 20] GeV/c for π, [0.3, 20] GeV/c for p... (ITS +TPC+TOF)
- Hardening of the spectra (more pronounced for protons)
- p_T shape ~unchanged after ~3-4 GeV/c

VII.1 – dN/dy : Λ/π, Ξ/π, Ω/π = f(mult)



ALICE, arXiv-1606.07424

1/ Consistent pattern between pp, p-Pb, Pb-Pb
for a given multiplicity

2/ Strangeness enhancement ↗ with strangeness content

Comparison with models :

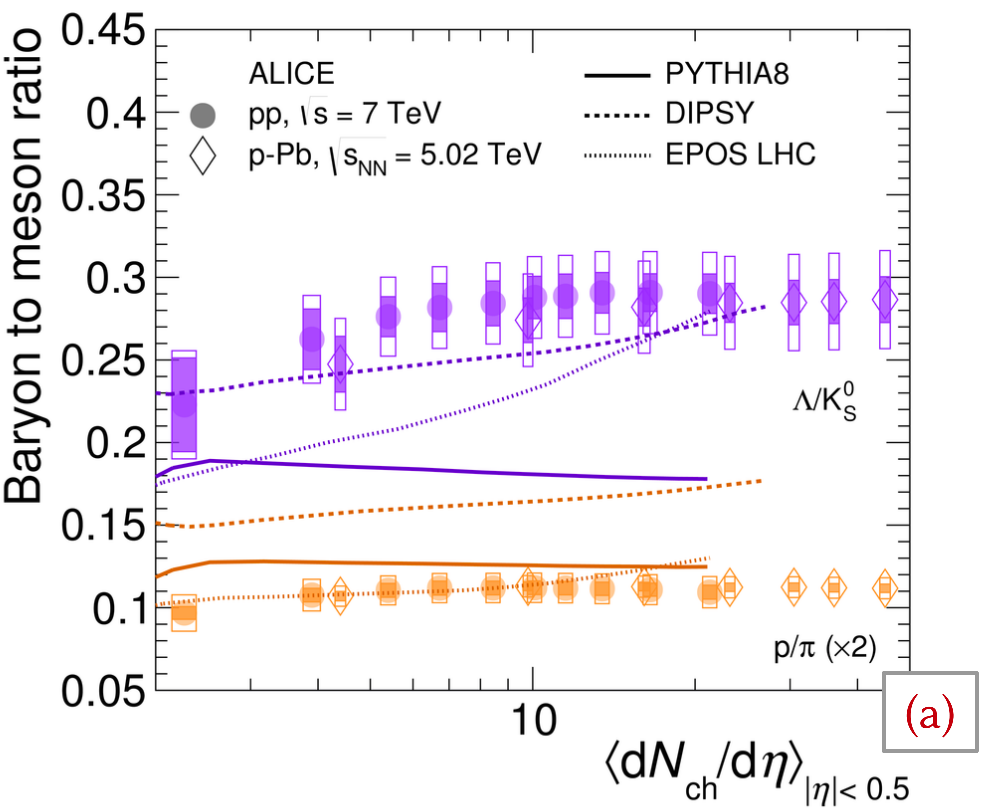
- **Pythia 8 Monash Tune** → strong disagreement
  Color Reconnection among Multiple Parton Interactions
  does not help (no matter On or Off…)

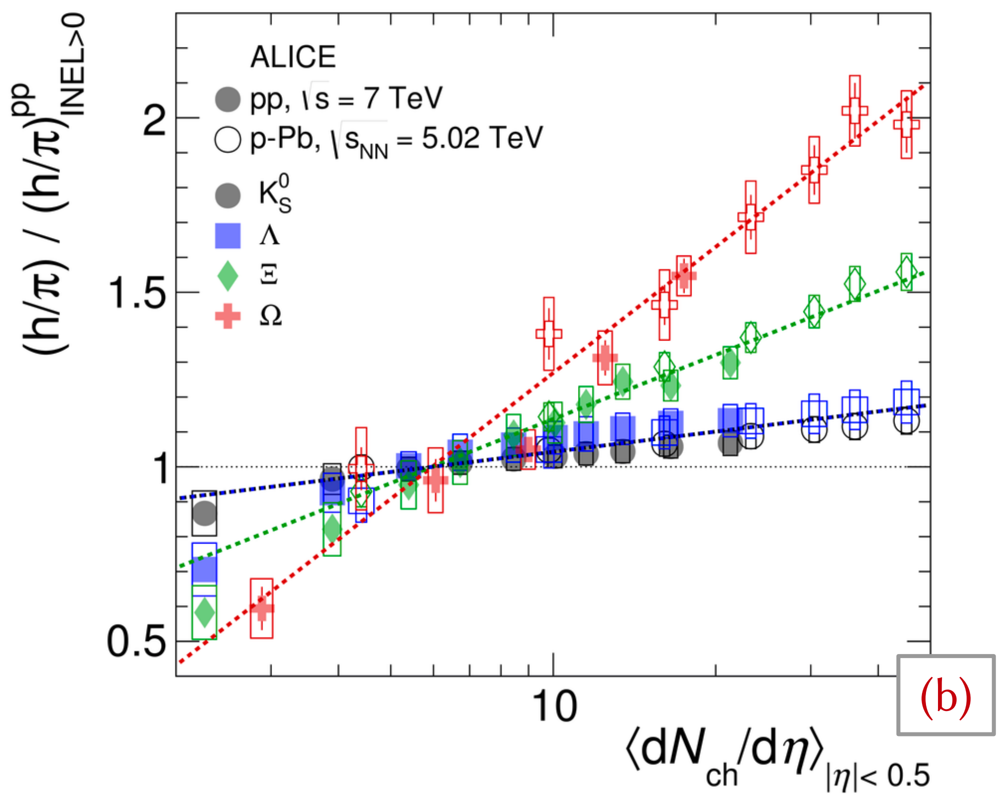
- **EPOS LHC** → cope with the general trend
  Core-Corona approach with multiple scattering
  but does not match the data straight away

- **DIPSY** → the best MC generator tested
  Color ropes seem to capture the main aspect ?
  but becomes off for Ω …
  but put too much stress on baryon (see protons, next sl.)

VII.2 – dN/dy : double ratio $[h/\pi]^{Ac[i]} / [h/\pi]^{INEL>0}$

How fast does the production of a given *h* species increase compared to $\pi^{\pm}$?
→ $[h/\pi^{\pm}]^{\text{event class } i} / [h/\pi^{\pm}]^{\text{INEL>0}}$

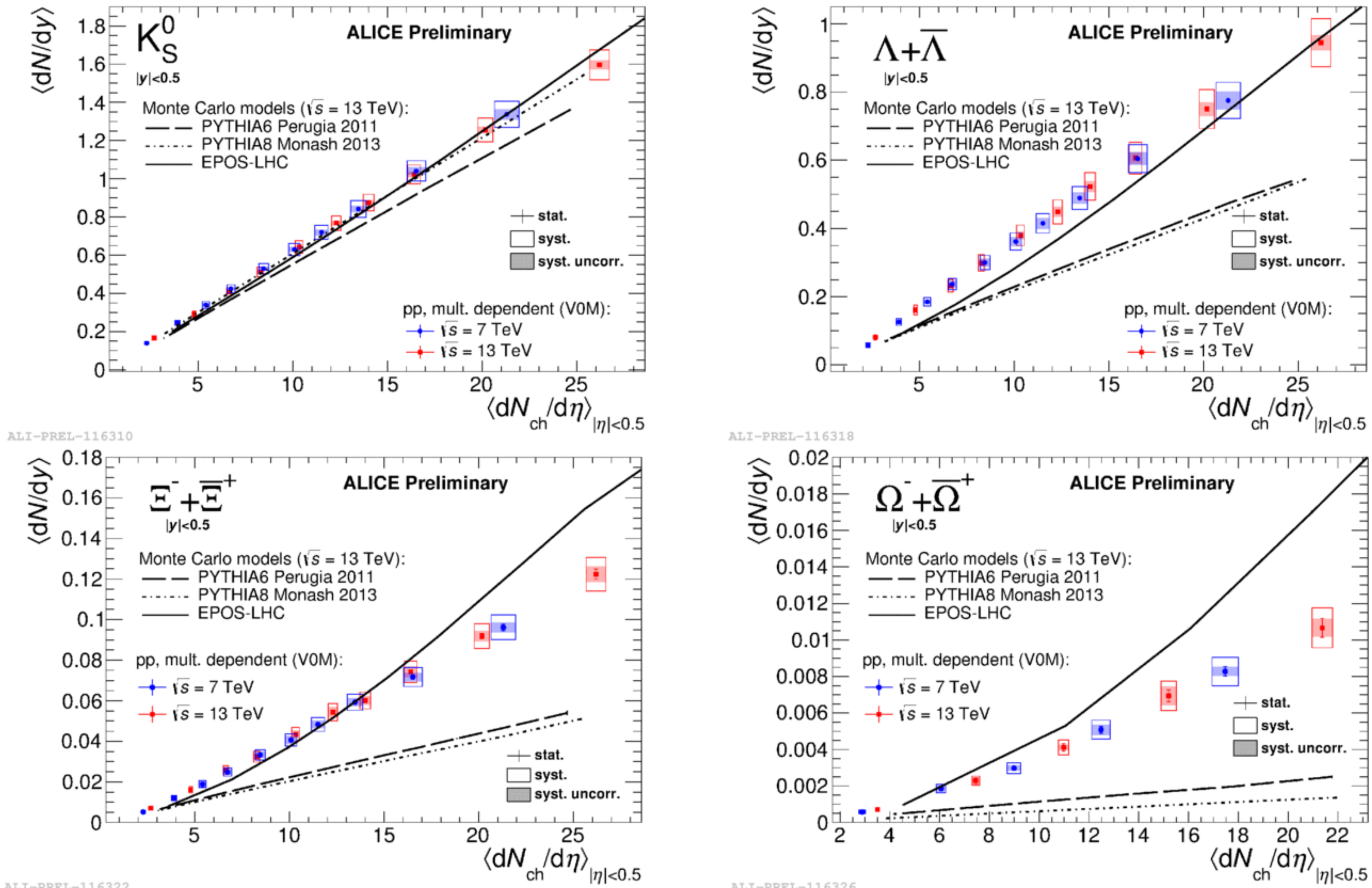




Test the effect of *mass difference* (a) and *strangeness* (b) effects
→ Not mass related (*p/π, Λ/K⁰s ~ constant*), but driven by strangeness content
i.e. the stranger, the greater relative increase with multiplicity

VII.3 – dN/dy : 7 TeV vs. 13 TeV

$\sqrt{s}$ does not seem to influence the trend → only dNch/dη seems to matter !



(c)

VIII.1 – Theory : Pythia 8 reaction

Thermodynamical String Fragmentation

https://arxiv.org/abs/1610.09818

Nadine Fischer, Torbjörn Sjöstrand

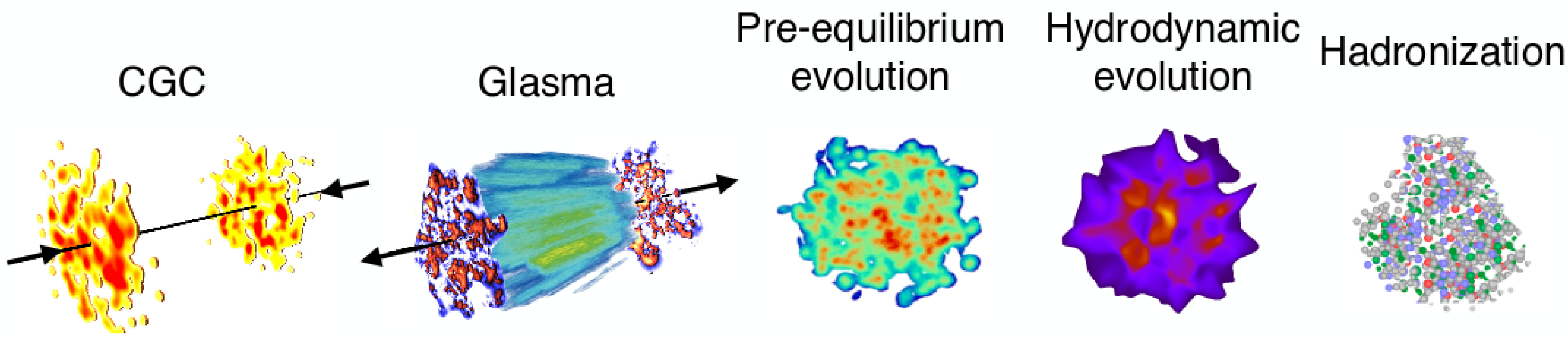
(Submitted on 31 Oct 2016 (v1), last revised 30 Jan 2017 (this version, v2))

The observation of heavy-ion-like behaviour in pp collisions at the LHC suggests that more physics mechanisms are at play than traditionally assumed. The introduction e.g. of quark-gluon plasma (~ **EPOS…**) or colour rope formation (~ **DIPSY…**) can describe several of the observations, **but as of yet there is no established paradigm**.

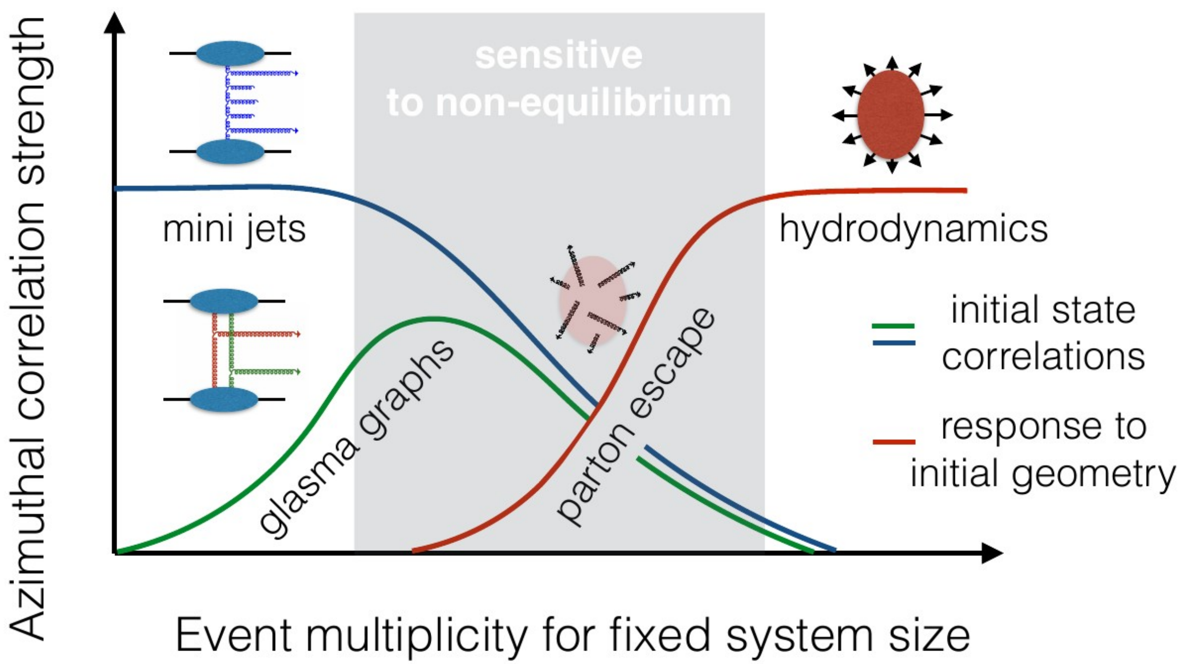
In this article we study a few possible modifications to the Pythia event generator, which describes a wealth of data but fails for a number of recent observations. Firstly, we present a new model for generating the transverse momentum of hadrons during the string fragmentation process, **(i)** *inspired by thermodynamics*, where heavier hadrons naturally are suppressed in rate but obtain a higher average transverse momentum. Secondly, close-packing of strings is taken into account by making the temperature or **(ii)** string tension environment-dependent. Thirdly, a simple model for **(iii)** hadron rescattering is added.

The effect of these modifications is studied, individually and taken together, and compared with data mainly from the LHC. While some improvements can be noted, it turns out to be nontrivial to obtain effects as big as required, and further work is called for.

VIII.2 – Theory : way out with Color Glass Condensate ?



Courtesy : Prithwish Tribedy (BNL)



Promising track...

Tribedy, arXiv:1611.00329

Summary

Strangeness enhancement already in high-multiplicity pp at LHC !

$1/\mathrm{Nevt}\ /\mathrm{d}^2 N/\mathrm{d}p_\mathrm{T}\mathrm{d}y = \mathrm{f}(p_\mathrm{T}$, V0M Activity) in pp 7 TeV

⟶ The enhancement is there in particular pp events, not only in Pb-Pb !
It goes along the way : "AA-like" collectivity in small system...

Note :

era of more and more differential analyses,
with the need to also stay quantitative (feedback to MC phenomenology) ...
⟶ ~ more and more complex analyses

Prospects :

Understand :
the microscopic (partonic) nature of "QGP",
+ the exact way its strong collectivity expresses
+ its onset

⟶ paradigm in MC phenomenology on the verge for changes/merging between pp and AA.
NB : mutual influence in conception, "AA ⟶ pp !" but beware also ... "pp ⟶ AA"

Appendices

A.1 – Mult. estimator : disjoint rapidity regions

“

4. Event normalisation

= how many events in my [a_1-a_2] % interval ?

→ raise the question of the inefficiencies in the event selection…
Is it free of bias for each species ?

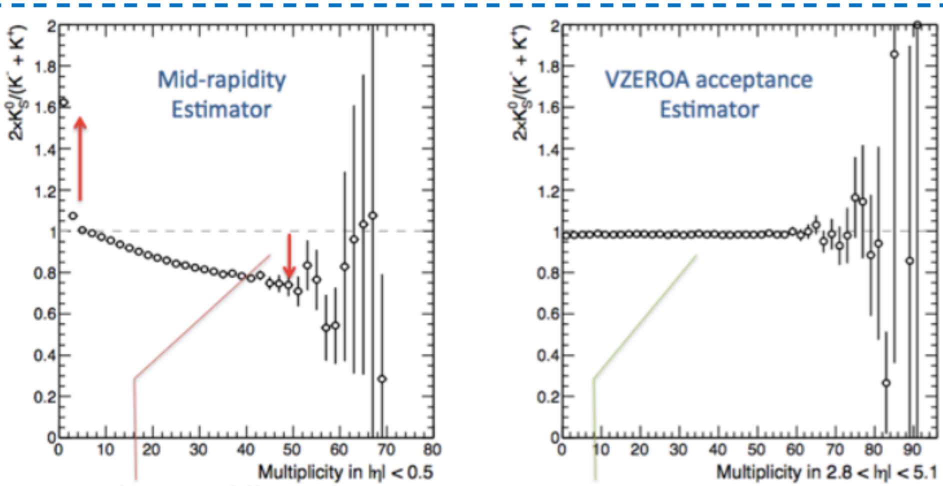
e.g. you want to study (Ω^- = 3 secondary tracks),
or (K^* = 2 primary-like tracks)
in an event class being N_{Ch} = [1-3] …

”

➔ Forward Multiplicity Estimator

Why is this important?

- Using mid-rapidity multiplicity estimators may introduce *self-correlation biases*, in particular towards charged particles
- For instance, it can be verified in simulations that the integrated yield ratio of charged to neutral kaons deviates from unity when selecting with mid-rapidity estimators



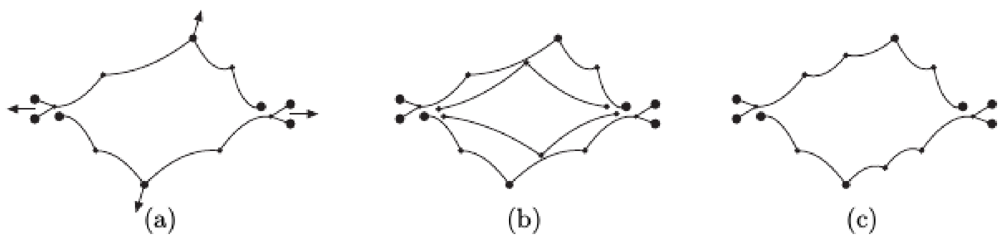
(~20-30% difference) (produced in equal amounts)

MC Studies: Estimator Biases

- PYTHIA Perugia-2011 (Tune 350)
- pp 7 TeV
- $K^{\pm}, K^0_S$ test

B.1 – Pythia 8 : ingredients, MPI + CR

Multi-Parton Interactions (MPI) and Color Reconnection (CR) mechanisms:

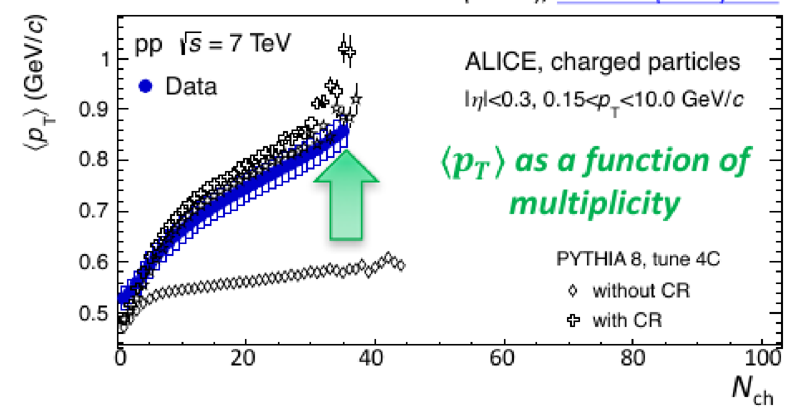


a) In a hard gluon-gluon subcollision, the outgoing gluons will be color-connected to the projectile and target remnants. Initial state radiation may give extra gluon kinks, which are ordered in rapidity

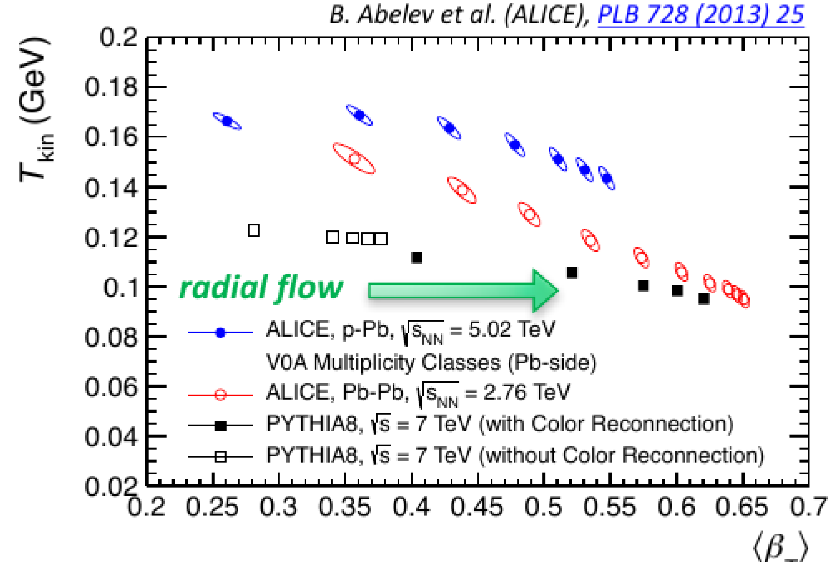
b) A second hard scattering would naively be expected to give two new strings connected to the remnants

c) In the fits to data, the gluons are color reconnected, so that the total string length becomes as short as possible

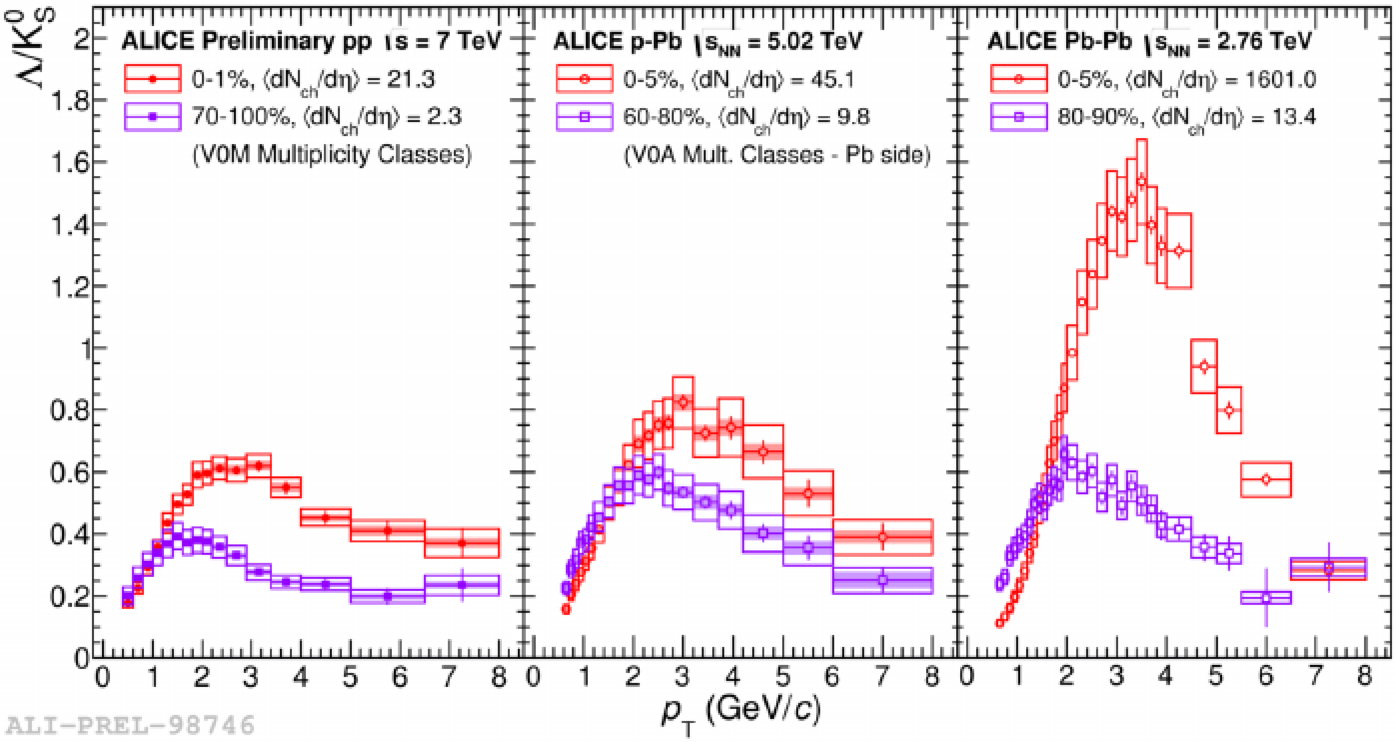
B. Abelev et al. (ALICE), PLB 727 (2013) 371



B. Abelev et al. (ALICE), PLB 728 (2013) 25



C.1 – AA-like : Λ/K^0_s in pp, p-PB and Pb-Pb



The ratio depends on the event multiplicity

in a **qualitatively similar** way as **in p-Pb and Pb-Pb**

The magnitude is smaller in pp with respect to p-Pb and Pb-Pb,

but note that for similar percentiles $\langle dN_{ch}/d\eta \rangle$ changes dramatically among the three systems